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ABSTRACT

This proceedings is devoted to the publication of research papers in mathematics, science, and technology education, covering domain/content areas such as learning and the learner, curriculum and materials, instruction, assessment and evaluation, history and philosophy of science, and teacher preparation and professional development. Papers in this volume include: (1) On the Development of Professional Development Program for Secondary School Science and Mathematics Teachers (Chorng-Jee Guo); (2) Effects of the Tansui River Education Program on High School Students' Environmental Attitudes and Knowledge (Shun-Mei Wang); (3) Taiwanese Elementary Students' Perceptions of Dinosaurs (Chi-Chin Chin); (4) The Relationship between Biology Cognitive Preferences and Science Process Skills (Yeong-Jing Cheng, James A. Shymansky, Chiou-Chwen Huang, and Bih-Ju Liaw); (5) Investigation of the Structure and Dimensionality of ILPS Tests Items (Miao-Hsiang Lin, Yeong-Jing Cheng, Song-Ling Mao, Hong-Ming Guo, Tai-Shan Fang, Jen-Hong Lin, and Jin-Tun Lin); (6) Linking STS Teacher Development and Certification (Cheng-Hsia Wang); (7) Continually Expanding Content Representations: A Case Study of a Junior High School Biology Teacher (Sheau-Wen Lin); (8) Expert Opinions Concerning a Taxonomic Structure for the Curricular Organization of Biotechnology (Jerming Tseng); (9) A Study of the Concept "Living Organism" and Living Organism Classification in Aboriginal Children (Shih-Huei Chen and Chih-Hsiung Ku); (10) An International Investigation of Preservice Science Teachers' Pedagogical and Subject Matter Knowledge Structures (Norman G. Lederman and Huey-Por Chang); (11) Empirical Review of Unidimensionality Measures for the Item Response Theory (Miao-Hsiang Ling); (12) Development of a Grade Eight Taiwanese Physical Science Teacher's Pedagogical Content Knowledge Development (Hsiao-Lin Tuan and Rong-Chen Kaou); (13) Identification of the Essential Elements and Development of a Related Graphic Representation of Basic Concepts in

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Environmental Education in Taiwan (Ju Chou); and (14) A Beginning Biology Teacher's Professional Development--A Case Study (Jong-Hsiang Yang and I-Lin Wu). (Author/DDR)

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(Invited Review Paper)

On the Development of Professional Development Program for Secondary School Science and Mathematics Teachers

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ABSTRACT

A professional development program was developed for in-service science and mathematics teachers attending summer school on campus. It was planned, tried out, evaluated, and revised as an action research. The primary goal of the program was for the participating teachers to obtain better theoretical understanding and practical experience about what counted as good teaching and learning of science and mathematics at the secondary school level. The program extended over a period of four years, and sufficient time and opportunities were provided for the in-service teachers to practise and reflect on what they had learned in the summer courses. Although contemporary theoretical viewpoints, especially constructivist perspectives, on the nature of science, the nature of science teaching and learning, and on science and mathematics teacher education had great impact on the development of this program, it was also strongly influenced by the experiences and findings that the author obtained from carrying out a series of related research studies in recent years with the collaboration of colleagues and graduate assistants. A review of these research studies is given, providing personal accounts of the interests and thoughts that led to the development of the professional development program. Following a summary of the rationales for the program's development, some of its key features are described. Based on informal assessment of the results obtained in its implementation, the practicability of the program is discussed. Potential impacts and implications of the program, especially for subsequent studies on science and mathematics teacher education, are also discussed.

Key Words: professional development, science and mathematics teachers, constructionist perspectives

I. Introduction

Research findings from studies of students' conceptions and learning of science (Driver & Erickson, 1983; Gilbert & Watts, 1983; Novak, 1988; Osborne & Freyberg, 1985) have led to extensive research efforts aiming at improving the learning and teaching of science from constructivist perspectives (Hand & Prain, 1995; Fensham, 1988; Tobin, 1993; Ramsden, 1988), which emphasize the active roles students play in learning, the importance of students' prior knowledge, the existence of higher order learning skills, and the viewpoint that learning amounts to conceptual change (Resnnick, 1983; Shuell, 1986; Wittrock, 1985). These perspectives are of particular significance to attempts at improving the teaching and learning of science in Taiwan, because traditionally science instruction at the secondary school level in Taiwan is for many students, and teachers alike, a preparation to perform well on tests. It is common to find students spending a great deal of time memorizing factual knowledge and solving contrived problems. Many students either become bored of learning science or study science without meaningful understanding. The situation for mathematics education is very much the same. Constructivism appears to provide a helpful framework for evaluating current practice and making reforms in science and mathematics education.

In order to improve the quality of science and mathematics instruction at the secondary school levels, it is desirable that science and mathematics teachers have a good understanding of the main ideas of constructivism, be familiar with a variety of teaching strategies that are consistent with constructivist points of view, and above all, be willing and skillful in putting constructivist ideas into practice. However, since most science and mathematics teachers were prepared under an educational system which emphasized the transmission of knowledge and competition among students, they tend to hold beliefs that run against constructivist ideas on the teaching and learning of science and mathematics. Clearly, it is a great challenge to educate science and mathematics teachers who can teach successfully in a constructivist manner. It was with this in mind, and for other reasons to be explained in the following, that the author decided in 1992 to initiate an action research project focussed on the development of a professional development program for in-service science and mathematics teachers.

A summer school offering graduate courses to in-service science and mathematics teachers was already in existence on our campus for a number of years by 1992. The in-service teacher education program at that time consisted of a total of twenty courses offered over four consecutive summers, covering areas such as subject matter content, theoretical foundations of science education, research methods, instructional strategies, and so on. Constructivism and other contemporary viewpoints on philosophy of science, cognitive psychology, and various instructional strategies for teaching science and mathematics were included in a few courses mentioned above. Although the introduction of constructivist perspectives on the teaching and learning of science and mathematics was received by the in-service teachers with some interest during the summer sessions, most of them tended to teach the same as before when they returned to their schools. Nevertheless, in recent years an increasing number of teachers have expressed strong interest in improving their teaching in accordance with constructivist viewpoints.

At the same time, the author had carried out a series of related studies, including the assessment of students' science process skills involving the use of science concepts, students' learning styles in studying science, students' misconceptions and alternative frameworks, instructional strategies facilitating students' conceptual change about force & motion, heat & temperature, elements & compounds, and chemical reactions, etc. As a result of these research efforts, the author and the collaborating faculty members had gained valuable experience in diagnosing students' conceptual understanding, in developing teaching strategies to facilitate students' conceptual change, and had explored the feasibility of setting up a new professional development program for science and mathematics teachers with constructivist perspectives as guiding principles. We felt strongly that we had the obligation and research foundation to make some major changes to the original program, and to develop a new one with a consistent set of goals, rationales, and strategic plans.

In order to show how the goals and rationales of the new professional development program were set up in accordance with our previous research findings, a review of three studies which the authors had conducted in recent years is given in the following section. It is interesting to note that a number of research groups worldwide had moved along the same line. In fact, in a similar layout, the papers included in a recent book edited by Treagust, Duit, & Fraser (1996) were organized into the following three parts: investigating student understanding of science and mathematics, improving curriculum and teaching in science and mathematics, and implementing teacher changes in science and mathematics.

II. Review of Three Prior Research Studies

Research findings of three prior research projects are given below. Original papers in English are available upon request.

1. Alternative Frameworks of Motion, Force, Heat, and Temperature (Guo, 1993)

The students investigated ranged from grade five to grade eight. Researchers developed paper-and-pencil tests used to probe students' conceptual understanding of a range of phenomena presented in problem situations. Analysis of students' responses yielded preliminary results on students' alternative conceptions. In each study, a number of students (approximately 10) having alternative conceptions which were shared by many students were selected for in-depth interviews. Students' alternative conceptions determined from both written tests and interviews were cross-checked and synthesized in order to identify students' alternative frameworks, which were defined as the underlying belief systems capable of explaining meaningfully the occurrence of these students' alternative conceptions. A summary of the results obtained is given as follows:

A. Alternative Frameworks of Motion and Force for Students in Grades 5 and 6 in Study A.

(a). Self-Centered Reference Frame

Students tended to take themselves as the reference point for describing the motion of objects, with the ground as an absolute reference frame.

(b). Position-Oriented Framework

The velocity of an object and the force it experienced were determined by simply considering its position relative to the other object.

(c). Motion-Oriented Framework

A moving object was thought to carry with it a force (or other quantity deemed to be the cause for producing the effect of motion), and that the faster an object moved the greater the force.

(d). Animate Framework

Force was thought to be produced only by living things that were able to move by themselves, such as animals and cars. Passive forces such as friction and gravity were often neglected or considered to be nonexistent.

B. Alternative Frameworks of Motion for Students in Grades 7 and 8 in Study B.

(a). Motion/Speed-Oriented Framework

Besides ideas similar to those held by the elementary students, the junior high students were found to possess the following alternative conceptions:

(1) A moving object was though to experience a force acting along the direction of motion. An object which was free from external force ought to be at rest.

(2) An object experiencing a constant external force would move with constant velocity on a perfectly smooth surface. An increase in velocity of an object moving in one dimension must be accompanied by an increase in the force which was acting on the object. A decrease of the latter was often thought to result in a decrease in the speed of the object.

(3) In the case of an elastic collision, a billiard ball was thought to experience no force upon impact with a solid wall, because the speed of the ball remained unchanged.

(b). Weight-Oriented Framework

For an object initially at rest to start moving, it must be subjected to a force which is greater than the weight of the object.

C. Alternative Frameworks of Heat and Temperature for Students in Grade 6 in Study C.

(a). Substantive Framework

For many students, heat was thought of as a sort of gas, foam, or vapor, there being hot and cold ones in a certain proportion for a body at a given temperature. The conduction of heat was thought of as the rising or diffusion of the hot stuff (molecules, or particles) from one end of a rod to the other, or from one thing to another.

(b). Equal/Undifferentiated Framework

Heat and temperature, often referred to as "hotness," appeared to be the same for many students. The temperature of a body was considered to be equal to the "heat" it contained.

D. Alternative Frameworks of Heat and Temperature for Students in Grades 7 and 8 in Study D.

(a). Substantive Framework

Alternative conceptions related to the substantive framework included:

(1) Heat was a sort of gas, like water vapor or smoke, and consisted of hot and cold gases.

(2) Matter conducted heat by means of "diffusion" of temperature, heat, or molecules.

(b). Equal/Proportional/Undifferentiated Framework

In addition to the alternative conceptions held by elementary students, junior high students were found to have the following alternative conceptions:

(1) Heat was a kind of force or energy, which was produced by temperature and was therefore proportional to it.

(2) The temperature of an object increased with continued heating, even during phase transition.

(3) The heat "absorbed" or "released" by an object was considered to be influenced by factors including mass and temperature change only.

(4) Heat was confused with or used interchangeably with temperature.

(c). Characteristic Temperature Framework

Temperature of an object was considered as its intrinsic property, with the effects of environment neglected.

(d). Passive Role Framework

Such a framework consisted of the idea that heat "absorbed" by water was stored within the "density" of water (meaning the vacant space in between the molecules), leaving water molecules unaffected. Or, as boiling water was kept heated, water temperature remained at 100 °C and the absorbed heat would "diffuse" into the air, leaving molecules in the water unaffected.

2. Improving Science Teaching and Learning: A Holistic Study Based on Constructivist Perspectives (Guo, Chiang, Tuan, & Chang, 1993)

The purpose of this study was to initiate an effort aimied at improving the teaching and learning of science at junior high school level, based on the viewpoint that teachers and students construct meaning in the process of classroom instruction. From the standard textbook currently used in Taiwan, four instructional units including heat and temperature, motion and force, elements and compounds, and chemical reactions were selected as topics for study. Prevalent alternative conceptions on these topics were identified before suitable instructional plans from a constructivist view were developed, tried out, and evaluated. The involvement of science teachers in developing the test instruments for probing students' alternative conceptions and in developing suitable lesson plans was built into this study, so that both teachers' development of a constructivist view of science teaching and students' concept learning results could be studied in a holistic way. Major findings include the following:

(1) Although the science teachers were willing to accept constructivist views of science teaching and learning, their preconceptions about science teaching were resistant to change. For instance, the belief that a clear presentation of well organized materials to the students was of utmost importance was still held by the science teachers at the end of the first year after they had participated in the project.

(2) The science teachers showed great interest in participating in the research activities. The development of test items aimed at probing students' understanding of science concepts was a valuable experience for them.

(3) Students' alternative conceptions identified in this study on motion and force, heat and temperature, and the molecular model of matter were very similar to those reported in the literature. It was noted that many students who had received formal instruction on the selected topics still held alternative conceptions similar to those of students who had not yet studied the same topics.

(4) It appeared difficult in the beginning for science teachers to develop their own instructional plans aimed at bringing about conceptual change in students.

3. Practicability of Constructivist Approaches in Science Teaching - A Case Study of Six Science Teachers in Taiwan (Guo, Chiang, Chen, & Wang, 1995)

This study was an integral part of the preceding project as it entered into the third (final) year. Efforts were made to answer the following questions concerning the science teachers participating in the research team:

(1) To what extent do science teachers have a grasp of the basic ideas of constructivism and their implications for science learning and teaching. How do the science teachers teach accordingly?

(2) What kind of experience would be helpful for science teachers to develop their belief in constructivism and skill in teaching science using strategies which are consistent with constructivist perspectives?

(3) What are the key factors affecting the practicability and effectiveness of including constructivist ideas in science teaching, particularly considering the existing educational and social-economic environment in Taiwan?

The study was carried out with the cooperation of four science educators, two junior faculty members, two graduate students, and six science teachers. The members of the research team were equally divided both in terms of sex and fields of specialty physics and chemistry. The four science educators, having many years of research experience in science education, were also actively involved in the in-service science teacher education program. Six experienced local science teachers were selected to participate in this study. They had been exposed to constructivism through a series of lectures in the in-service science teacher education program. Four of them had participated in our research group for two years, while the other two had just joined us at the start of this study.

A qualitative case study approach was used to gather data from classroom observations, interviews, and relevant documents. The data obtained for each science teacher was organized to form a case record, which were then compared, consolidated, and interpreted in order to come up with the following general conclusions.

(1) The science teachers tended to take constructivist

ideas towards teaching and learning mainly as new teaching approaches towards concept learning and conceptual change, and focussed on ideas which were consistent with their own teaching beliefs, styles, and practices. Although they were able to come up with plans and activities which were conducive to constructivist teaching and thus providing more opportunities for students to think, question, and discuss, their major concerns towards and beliefs in science teaching were essentially the same as before. To be sure, some changes in teaching behavior were observed. For instance, they tended to ask more questions which were important for a meaningful understanding of some key concepts, and often requested students share examples from daily experiences in order to illustrate certain concepts and principles under study. Nevertheless, teachers' desire to cover scheduled topics and students' desire to do well in written examinations often forced them to return to the use of traditional, direct teaching methods, which they felt to be straightforward and less time consuming.

(2) It was noted in this study that regularly scheduled meetings and practical experience in conceptual change teaching strategies, including probing students' misconceptions and designing instructional plans, were of great significance to the implementation of a constructivist teaching approach by science teachers. In addition to providing opportunities for self and group reflection, they seemed to provide a vehicle for the science teachers to develop a better understanding of constructivism, and to build confidence in its relevance to science education.

(3) It was also noted that there were other important factors influencing the practicability and effectiveness of constructivist teaching, such as students' study skills and learning strategies, appropriate ways to evaluate students' achievement, and school and parents' support for and confidence in the science teachers. The science teachers in this study were experienced science teachers who knew how to guide students to study differently from what they were used to, and to convince students, parents, and school administrators that the long-term effects of a constructivist teaching approach ought to be very beneficial. Nevertheless, the ensuing challenges and pressure were very noticeable.

III. Program Development Rationales and Implementation Strategies

Since professional development is tied to salary raises and retirement pensions, the in-service teachers attending the summer school on campus were admitted through a competitive selection process favoring experienced teachers. Typically, they had at least five years' teaching experience and were selected either because of involvement in some sort of administrative work or because their students performed well in academic activities such as science exhibitions, science contests, and so on. They tended to be highly motivated teachers, and were usually considered to be good teachers in their schools. Their teaching viewpoints and techniques are, however, very traditional and monotonous. In view of recent calls worldwide for reform of science and mathematics education by emphasizing constructivist approaches to teaching and learning, the interaction of science/technology/society, improving students' scientific literacy, etc., it is very desirable that the in-service teachers' viewpoints on the teaching and learning of science and mathematics should be widened and brought up to date. Therefore, the primary goal of the professional development program developed in this study was to provide learning environments and activities in such a way that the attending teachers would be able to construct for themselves a better understanding of contructivist viewpoints on science and mathematics teaching and learning, and would be able to put them into practice in their own classes. Furthermore, they were expected to play leadership roles in encouraging and working with their peers to improve science and mathematics teaching at the classroom and school levels.

Based on previous research findings, our rationales for developing a new professional development program to obtain the above goals were as follows:

(1) Teachers' conceptual understanding of and belief in what counts as good science and mathematics teaching are hard to change. It takes time and effort for this to occur.

(2) There are cognitive and affective/social factors which must be taken into account when one attempts to induce change in teachers' beliefs, conceptual frameworks, teaching behaviors, etc. The former has to do with the teachers' own evaluation of the intelligibility, plausibility, and fruitfulness of constructivism, as suggested by the conceptual change model of Posner, Strike, Hewson, and Gertzog (1982). While the latter involves motivation, self-efficacy, peer

pressure, societal expectations, administrators' support, and so on.

(3) In order for the teachers to be able to teach in a constructivist manner, they must be taught in the same way. That is, ideally, teachers must be taught the way they are expected to teach.

(4) In order to have a good grasp of the essence of constructivist approaches to teaching, teachers need to put what they have learned into practice with careful planning and constant reflection. Simply listening to a few lectures on constructivism is not going to cause any noticeable change. Reflection in action and knowledge from action are keys to a better understanding of constructivism.

(5) In addition to content and pedagogical knowledge, it is very important for teachers to be able to assess students' prior knowledge, alternative conceptions, development in conceptual understanding, science process skills, and learning styles. Teachers should be able to help students meaningfully learn science and mathematics, based on the information gathered through the above assessments. In short, a teacher's pedagogical content knowledge is important.

Consistent with the above goals and rationales, a number of strategies were adopted in the implementation of the program.

(1) The program consisted of a total of twenty summer courses, which were designed to help the in-service teachers carry out action research aiming at improving science or mathematics instruction in their own classes when they returned to school to teach. This should lead to putting theory into practice, and a spreading of professional development efforts from summer sessions to all year round. The teachers were encouraged to carry out action research collaboratively with their peers from the summer school, or with other teachers in their own schools.

(2) From choosing a research topic to the publishing of research results, the entire process was divided into four stages, with summer courses providing needed guidance in each stage over a period of four years. For instance, courses in the first summer focused on the nature of science, the goals of science education, constructivism, conceptual change teaching strategies, and so on. Courses in the second summer focused on research designs and data collection methods (including assessment of students' learning styles, misconceptions, and skills in problem solving), teaching techniques, classroom management, and educational technology. Courses in the third year included analyses of both quantitative and qualitative data, the writing of research reports, and so on. Other courses such as educational administration, STS, integrated science, and so on, were included in the fourth summer.

(3) At least two-thirds of the summer courses were taught by faculty members participating in the research group. These courses were taught in a manner consistent with constructivist ideas about teaching and learning. Various instructional strategies such as learning cycles, Gowin's V-diagrams, problem-centered activities, and so on were used. Collaborative projects and group discussions were commonplace, and the in-service teachers were given the shared right to decide course contents, evaluation methods, and so on. Some courses were taught by a team of two to four professors, providing a working model of collaboration.

(4) An action research project was built into the development of the professional development program, in order to evaluate its practicality and effectiveness. A number of in-service teachers, typically four to eight in each year, were chosen to participate in our research group. They maintained close contact with the university faculty. Their classroom teaching and research activities were studied by other members in the research group.

(5) Various kinds of supports were provided to the in-service teachers, particularly to those participating in the research group, so that they would be able to carry out their own research efforts in improving teaching and learning, while at the same time learn to assume leadership roles in science and mathematics education reforms. This support included correspondence by phone and mail, visits to their schools and principals, helping them to hold workshops on constructivist ideas and practices in teaching science and mathematics, and circulation of bulletins on constructivism and constructivist approaches in teaching. The use of the Internet has also become popular lately.

The development of this professional development program was based on our understanding of constructivist approaches to the teaching and learning of science and mathematics, and on our research experiences obtained from previous related studies. It was developed from a vision of science and mathematics education for the 21st century, and an understanding of existing educational and socio-economic conditions in Taiwan. Although it was not modelled after any particular program, the underlying themes seemed to be close to those described by Doyle (1990) as the "innovator paradigm" and the "reflective professional paradigm". With reference to these themes, teacher education should be a source of renewal and innovation for schools, and should foster the reflective capacities of observation, analysis, interpretation, and decision making. The practicality and effectiveness of the program, to be discussed in the following section, should be viewed with such an orientation too.

IV. Practicality and Effectiveness of the Program

As Doyle (1990) pointed out that, with the thematic shift in teacher education research, quality control should be based not on a system of external control but on the available knowledge about content and about practices and their implementation in the classroom. Instead of asking whether a practice appears to be effective according to external criteria used, the accountability question becomes, is the appropriate knowledge being used in this situation? As an action research, qualitative data including video tapes of classroom observations, interviews, teachers' instructional plans, students' journals, and so on were collected, analyzed, and cross-checked in an attempt to answer questions about the practicability and effectiveness of the program. As the in-service teachers who first entered this program in 1994 are still in their third year, a complete evaluation of the entire program will not be available until the end of 1998. However, from informal assessments of the results obtained so far, we have noticed that most of the teachers were able to do what they were expected to with varying degrees of success.

Evaluation of the practicability and effectiveness of the program in the context of current educational practices in Taiwan is greatly influenced by the fact that competition to enter better senior high schools and universities has become a major public concern. Although measures have been taken by the Ministry of Education to lessen such competition and its negative effects on education, no real progress has been achieved so far. Many schools still secretly divide their students into classes consisting of students considered to be of different abilities, paying greater attention to teaching the brighter students who appear to have better chances of doing well in the entrance examinations. There were many anecdotes told by the in-service teachers about their successes in teaching classes consisting of what used to be considered lower ability student, using constructivist approaches. Students who were proviously deemed as stupid, naughty, or reckless were found to participate and often do well in discussions and hands-on activities. The real challenge lies, however, in teaching classes with higher ability students. Parents and school administrators were reluctant for teachers to try anything new on them, because they were worried that it would lead to harmful results on students' achievement tests. This pressure was so high that many teachers dared not deviate from their current teaching practices in these classes. However, approximately 10% of the in-service teachers were convinced of the merits of a constructivist approache after taking the first summer courses and were confident enough to put them into practice during the following school year. They bought back encouraging experiences to share with their classmates in the summer of the next year. With such input and further summer courses designed to enhance better understanding of constructivism and a variety of instructional skills, most teachers became motivated and confident enough to make certain changes in their teaching following the second summer. In a sense, our program appeared to be practical and effective. Nevertheless, some of the in-service teachers still found themselves facing the dilemma of whether to teach in a constructivist manner consistently or just to do it once in a while as a supplement to traditional teaching method focusing mostly on memorization and solving problems designed for paper-and-pencil tests. It would be interesting to see how teachers' decisions on such matters evolve as time goes on, and what are the important factors influencing their decision making. These are, in fact, the research questions of the thesis of a Ph.D. candidate surpervised by the author.

V. Concluding Remarks

The goals, rationales, implementation strategies, and practicality of a professional development program developed for in-service science and mathematics teachers were described in the above sections. The main purpose was to summarize the thoughts and efforts that went into developing the program, based on the author's understanding of contemporary theoretical perspectives on science education, the perceived educational needs of science and mathematics teaching in Taiwan, and the research findings of related studies headed by the author in recent years. It was meant to serve as an illustration of how one might combine research with practice in an effort to make a contribution to the reform of science and mathematics education. In this respect, it appeared to be excusable to not include comprehensive reviews of related literature and more detailed information of the program in this article. It must also be pointed out that although constructivism was refered to as a guiding principle in developing the program, it was by no means considered as a panacea for solving all problems in science education. In the professional development program, the in-service science teachers were provided on opportunity to reconstruct their viewpoints of the nature of science and mathematics, the nature of the learners, and the nature of the teaching of science and mathematics. They were not forced into believing or doing anything that did not make sense to them.

Although determining the effectiveness of the program and its potential impacts on the in-service teachers and their students must await further studies in the near future, it is perhaps worthwhile mentioning some of its implications for other reform efforts in science and mathematics education. In carrying out the development of the professional development program as an action research, the author and the collaborating faculty members made frequent contact with the in-service teachers, their school principals, and other educational administrators, and were able to bring to their attention that meaningful understanding and scientific literacy are important goals, and that constructivist teaching approaches have much to offer in reaching these goals. In addition, a few principals were so impressed with the improved performance of their science or mathematics teachers from the program that they wished we could also help their science and mathematics teachers, and even those in other subject matter areas to teach in a constructivist manner. This is certainly something worthwhile for our research agenda in the near future.

Another potential impact of the program has to do with the preparation of presevice science and mathematics teachers. With the advent of the 21st century, calls for reform of education have been put forward all over the world in recent years. Taiwan is no exception. Some steps have been taken by the Ministry of Education in an effort to bring about changes in existing educational practices. For instance, with the recent legislation regarding the diversification of teacher education programs, the responsibility for the preparation of teachers will no longer lie on normal colleges and normal universities. Instead, colleges and universities offering teacher education programs will be eligible to prepare prospective teachers, who will be engaged in a practicum for one year before they are hired by schools and local educational authorities. It is obvious that the in-service science and mathematics tearchers participating in the professional development program will be able to play very important roles in serving as mentors for the preservice teachers in their practicums, and helping in the selection of qualified new teachers at the local school level. In fact, concerns in this regard had led the author to carry out a project entitled "A Study on Educational Practicum and Certification of Junior High Mathematics and Science Teachers" beginning in April 1995. This consisted of several sub-projects headed by collaborating colleagues, with research questions focussed on the description of the personal traits of student teachers and their environmental factors, the development of models of practice teaching, the identification of desired teacher competencies and the observation of student teachers' actual performance in classroom situations, etc. Three common themes, namely constructivism, pedagogical content knowledge, and portfolio development provide unifying threads which run through all the sub-projects. Evidently, there are valuable experiences and research findings from the professional development program project that these studies can build on.

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有關中學數理教師在職進修學程發展之回顧

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摘　　要

本文報導一項中學數理教師暑期進修學程的發展，此項工作係以行動研究方式進行規劃、試用、評估、和修訂。其主要目的在於促使進修教師對於何爲良好的中學數理教學具有較佳的學理上的瞭解和實務上的經驗。此一進修學程前後持續四年，在此期間特別設法促使進修教師有充分的時間和機會，得將暑假上課所學的理念和方法，在平時的教學中實際加以運用、檢討、和改進。本學程的發展雖然深受建構主義等當代科教思潮對於科學的本質、數理教學的本質、以及數理師資培育的觀點之影響，但許多有關的理念和作法係奠基在作者及共同研究人員近年來一系列相關研究所累積的經驗和獲得的成果之上。文中摘述這些研究的重要成果，以便對發展此一在職進修學程的旨趣和理念提出說明。在綜述發展此學程的基本理念之後，對其主要特色有所描述。根據試用期間的評估，在文中亦論及其實際施行的可行性。最後略述此一學程在數理師資培育方面可能產生的影響及啟示。

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Effects of the Tansui River Education Program on High School Students' Environmental Attitudes and Knowledge

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ABSTRACT

Like many other places on the Earth, most rivers in Taiwan are polluted. Educational programs are needed to raise the public's concern about rivers and motivate them to take action. The Tansui River Education Program (TREP) was designed for secondary students in the Tansui River watershed of Taiwan. The pilot TREP was conducted in two high schools to evaluate the program's effects on attitudes and knowledge. The experimental design included control and experimental groups, pre- and post-tests and a questionnaire. A paired t-test and a one-way ANOVA with a 0.05 level of significance were used to analyze the data. Due to an inflexible regular curriculum, the two-day pilot program was conducted outside of class during weekends and holidays. The control group did not receive any instruction and only answered the questionnaire. Major findings of the research were: (1) TREP significantly increased participants' awareness of the river; (2) TREP significantly increased their sense of empowerment for saving the river; (3) TREP significantly increased their intention to take actions related to "advocacy" and "school environmental protection"; (4) TREP significantly increased their feeling of responsibility for the school environment in terms of planning and decision making; (5) TREP significantly increased their knowledge of water quality. In light of the research results, the author suggests that the Ministry of Education in Taiwan should consider adding TREP to the national curriculum.

Key Words: water monitoring, river education program, evaluation, environmental attitudes, knowledge of water quality.

I. Introduction

The environment is a type of social issue; this issue is related to human beings' values, beliefs, and awareness about the environment and environmental protection (Stapp, 1983). About 30 years ago, people began to be aware of the environmental crisis and environmental protection movements began in western countries (Swan, 1975) and Japan (Song, 1989). Gradually people began to understand the importance of environmental education in addressing the root causes of environmental issues – indifference toward the environment and lack of knowledge about the environment.

The issue of river water quality is one of the most critical environmental issues around the world, particularly in Taiwan. The middle and lower reaches of most rivers in Taiwan are moderately to seriously polluted (Environmental Protection Administration, 1989). Although technical and political efforts to save these rivers, such as building sewage systems and law enforcement to prohibit illegal dumping have been undertaken, river education programs are needed to increase the general public's concern for the rivers and motivate them to be involved in the tasks of improving the rivers' water quality. This research consisted of the design of the Tansui River Education Program (TREP) and its evaluation.

II. Tansui River Education Program (TREP)

TREP focused on the Tansui River watershed, which is the largest river system in the north of

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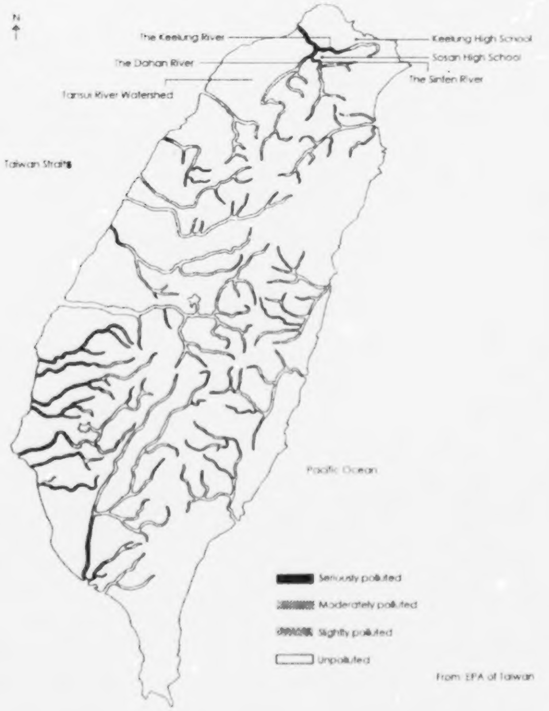
Taiwan. Its three branches, the Keelung River, the Sinten River, and the Dahan River drain a watershed that includes 27 cities and a population of more than 4.6 million (Fig. 1). Various land uses have seriously polluted the Tansui River and the water quality is usually very poor (BOD> 18 ppm) in its middle and lower reaches.

The overall goal of TREP was to motivate students to be concerned about this watershed and take actions to improve river quality. In order for this to occur, the following four subgoals of TREP were set:

(1) To increase participants' awareness of current status of the Tansui River
(2) To promote participants' environmental attitudes and empowerment
(3) To enhance participants' knowledge of river water quality
(4) To increase participants' skills in water monitoring and problem solving

These subgoals match the aims, characteristics and hierarchical objectives of global environmental education, including awareness, knowledge, attitudes, skills, and participation. (UNESCO, 1980) In addition, Hines' meta-analysis (Hines, Hungerford, & Tomera, 1986) also pointed out that attitudes, empowerment, knowledge and skills are important variables in building an environmentally responsible citizen. In this research, the effect of TREP was examined by assessing the students' awareness, attitudes and knowledge.


N
The Keelung River
The Dahan River
Tansui River Watershed
Keelung High School
Sosan High School
The Sinten River
Taiwan Straits
Pacific Ocean
Seriously polluted
Moderately polluted
Slightly polluted
Unpolluted

From EPA of Taiwan

Fig. 1. Program area: The 21 main rivers in Taiwan and their pollution status, three main branches of the Tansui River and the location of Keelung High School and Sonsan High School.

TREP consists of five sections (Fig. 2): (1) Students shared their experiences and expectations of the Tansui River within groups involved in the program. (2) Students learned about the Tansui River and its problems through a slide presentation in order to get an overview of the river. (3) Students monitored river water with nine tests and investigated land uses along the Tansui River near their school in order to understand the interaction between human activities and river water quality and build skills in using water monitoring testing kits and analyzing water quality data. (4) Students read a story about citizens successfully taking action to stop illegal fishing in a small village of Taiwan in order to learn about citizens' environmental responsibilities and problem solving strategies. (5) Students undertook collective actions in their school in order to increase public awareness of the Tansui River's problems.

The program adopted the interdisciplinary and community problem solving approaches used in the Rouge Project (Bull *et al.*, 1988). The program combined natural science investigation and social science discussion to understand the big picture of water quality and how it is related to social issues. The environmental issue focused on was river water quality near

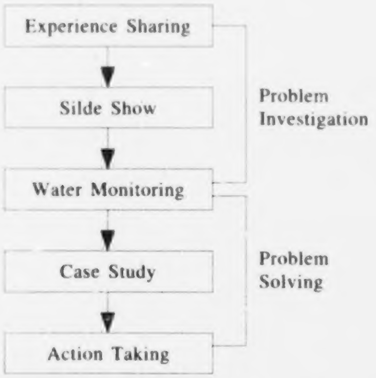

Experience Sharing
Silde Show
Water Monitoring
Case Study
Action Taking
Problem Investigation
Problem Solving

Fig. 2. The five sections of the Tansui River Education Program.

the schools. Students collected information on the river, learned citizen action strategies and processes and gained direct experience solving real world issues.

TREP adopted two attitude change approaches – changing attitudes by giving information and letting students learn by doing. Festinger's cognitive dissonance theory (Festinger, 1957) holds that a person's cognition, attitude and behavior must usually be consistent in order for the person's psyche to be in balance. He asserted that individuals cannot tolerate a psychological state of dissonance. The state of dissonance causes an uncomfortable tension and drives people to search for information, change their attitude, or change behavior to reduce or avoid an increase in cognitive dissonance.

The slide show and case study sections of TREP provided information concerning sense of responsibility for the environment and the impact of some common behavior on rivers. When students learn new messages or truths concerning the target, at the same time they learn values and attitudes toward the target (Koballa, 1988). However, the process of informing, assimilating, and confirming is conducted by the learner's existing cognitive system (Phillips, 1981; Kaplan and Kaplan, 1982). Inculcation and value clarification approaches were applied in the slide show and case study sections to build students' attitudes and knowledge.

Another effective learning approach is first-hand experience. Direct experience using more than one of the senses can build more comprehensive concepts and help the learner retain the concepts longer than learning by symbols only (Fazio and Zanna, 1981). Engleson (1985) views direct purposeful experiences in the field as able to benefit students' awareness of the environment and their environmental responsibility. TREP provided direct experience in the water monitoring and action-taking sections, which created another opportunity for attitude change.

Another approach – changing subjects' behavior to lead to a change in their attitude was also applied in TREP. According to Festinger's cognitive dissonance theory (Festinger, 1957), people usually change their attitude toward a target in public decision making and compliant behaviors. Following a decision, there is a process of actively seeking out information which is consonant with the decision, strengthening confidence in the decision and increasing attitudes in favor of the alternative chosen (Festinger, 1957). Zimbardo, Ebbbesen, & Maslach (1977) explained that a person does not make questionable inferences about his public behavior. Therefore, the person usually maintains his behavior and changes his attitudes toward the behavior privately to match the behavior.

By participating in TREP and going outside and monitoring river water in the field, students were persuaded to adopt more positive attitudes toward water monitoring. In the action-taking section, students were asked to develop their action plan, make decisions and take actions in front of other students – a compliant behavior. After this section, their attitudes toward the actions they took and the working process often changed.

Petty (1986) classified two types of persuasion processes, the central route and peripheral route. The central route provides subjects with abundant information in order to help them carefully consider the information and change their attitudes. The other way is to create social pressure or a reward to induce a person to change his or her attitudes. TREP sought to change a person's attitude using these two approaches at the same time.

III. Research Methods

The design of this research was based on the "pre-test/post-test nonequivalent control group design." This design tried to control for the effect of history and checked for any differences between the experimental and control group concerning the environmental attitudes and knowledge. Eight classes (four from Keelung High School and four from Sonsan High School) were selected by school teachers to participate in this research. Keelung High School and Sonsan High School are located along the Keelung River, one branch of the Tansui River (Fig. 1). The two schools are very different. Keelung High School is in a suburban area, while Sonsan High School is a typical urban school. The water quality near Keelung High School was good. However, the river near Sonsan High School was polluted.

Four classes – two classes each from Keelung High School and Sonsan High School participated in TREP as experimental groups and answered the pre- and post-test questionnaires (Appendix A). TREP was conducted by the researcher and the teachers during two days of seven hours each over weekends or holidays, outside of classes, due to the highly structured class schedule during weekdays. Most participants were voluntary. Three-quarters of the participants (105 students) participated in whole program (Table 1).

There were also four control classes which corresponded to the experimental classes in terms of their major area of study and academic performance. During the research, the control classes answered the pre- and post-test questionnaires without attending any of the

Table 1. The Experimental Design of the TREP Program

Groups	No.	Pre-test	Program	Post-test
Experimental classes				
Full participants	105	X	whole	X
Partial participants	47	X	partial	X
Non-participants	22	X	none	X
Control classes	176	X	none	X

program.

To evaluate the program, an evaluation instrument was designed according to the program objectives of awareness, attitude, and knowledge. This was a questionnaire consisting of five parts (Appendix A). The questionnaire was modified based on the comments of a panel of 11 educators who had experience in environmental education or educational evaluation. These experts reviewed it according to the objectives and content of the program.

The reliability of the "attitudes" and "confidence about water quality knowledge" sections of the questionnaire was calculated using a Chronbach alpha with SPSS software to check internal reliability (Table 2). The reliability test for the "knowledge of water quality" section was conducted using the split-half method. The reliability coefficients for most parts were higher than 0.65 and were therefore accepted. Because the construct of "attitudes toward saving the Keelung River" is diverse, the internal consistence is low. However, the situation of low internal consistence was overcome in analysis because each dimension of this part had its own score, rather than being combined to get the score of the part as a whole.

The data analysis included descriptive and inferential statistics. The assumption for normality was tested by the skewness and kurtosis processes. Most results indicated no serious departure from normal distribution. The assumption for equal variance was met by a residual error term. Therefore, the paired t-test was used to analyze the change between the pre-test and post-test of most parts of the questionnaire, except the "awareness of the river" and "attitudes toward saving the river" sections. The one-way ANOVA analysis was used to detect the difference between the four groups in the pre-test and the post-test. The level of significance for these statistics was set at 0.05.

The "awareness of the river" and "attitudes toward saving the river" sections had to be analyzed differently in the pre- and post-test comparison, because the post-test of the two parts were included in student evaluation sheets which did not include students' names. Thus, the pre-test and post-test results in these two parts could not be matched individually. This caused the pre-test and post-test scores for these parts to be dependent. The difference between pre- and post-test results was analyzed with one-way ANOVA and the significance level was set as 0.01 to overcome the "dependent variable" issue.

The research had three constraints to interpreting the data. First, the results were not able to show that TREP is more effective than a regular lecture approach or any other approach, because the control classes did not receive any of instruction. Second, it cannot be assumed that the program effect would have been exactly the same if the program were conducted during regular class time. Third, using the same questionnaire for the pre- and post-test may have caused a postponed effect.

Overall, the research dealt with program effects in terms of attitude and knowledge and was carried out using the following five null hypotheses.

(1) There is no significant difference in participants' awareness of the studied river in the pre- and post-test for TREP.

(2) There is no significant difference in participants' attitudes toward saving the river in the pre- and post-test for TREP.

(3)(i) There is no significant difference between the control group and the experimental group in terms of feelings of responsibility for

Table 2. Reliability Coefficient for Each Section of the Questionnaire

Section	Coefficient of Reliability
Awareness of the Keelung River	0.68
Attitudes toward saving the Keelung River	0.35
Knowledge of water quality	0.87
Confidence about water quality knowledge	0.80
Attitudes toward responsibility for environmental protection	0.66
Intentions of taking environmental actions	0.71
Perceptions of barriers to action taking	0.76

Table 3. Pre- and Post-test Comparison of Awareness of the Keelung River

Name of school Dimensions	Mean		Difference between two tests	F value	P
	Pre-test	Post-test			
Keelung School					
Familiarity with river	3.98	5.67	1.69	63.06	0.000
Evaluation of river's health	2.61	4.27	1.66	69.10	0.000
Good feelings about river	2.91	4.02	1.11	28.63	0.000
Sonsan School					
Familiarity with river	3.62	5.49	1.87	49.96	0.000
Evaluation of river's health	2.03	2.35	0.32	2.46	0.120
Good feelings about river	2.36	2.56	0.21	0.93	0.336

Note: Score is from 1 to 7.

environmental protection after TREP.

(ii) There is no significant difference between the experimental group's pre-test and post-test in terms of feelings of responsibility for environmental protection.

(4)(i) There is no significant difference between the control group and the experimental group in terms of intention to take action after TREP.

(ii) There is no significant difference between the experimental group's pre-test and post-test in terms of intention to take action.

(5)(i) There is no significant difference between the control group and the experimental group in terms of the knowledge of river water quality after TREP.

(ii) There is no significant difference between the experimental group's pre-test and post-test in terms of knowledge of river water quality.

(iii) There is no significant difference between the control group and the experimental group in terms of their confidence in their knowledge after TREP.

(iv) There is no significant difference between the experimental group's pre-test and post-test in terms of their confidence in their knowledge.

IV. Result and Discussion

1. Students' Awareness of the Keelung River

Null hypothesis 1 (familiarity with the river) is rejected according to an ANOVA test with 0.01 significance level. TREP significantly increases participants' awareness of the Keelung River in terms of familiarity of the river. The mean differences between the pre- and post-tests of the experimental groups at Keelung High School and Sonsan High School were 1.69 and 1.87, respectively.

Students' awareness of the river was measured according to three dimensions: their familiarity with the river, their evaluation of its cleanness, and their feelings about it. After the program, the participants ranked their level of familiarity with the Keelung River as higher than before the program (Table 3). Before the program, they were not familiar with the river. However, students evaluated the Keelung River as very polluted and felt negative about it.

In addition, the program helped participants clarify their perceptions of the river's health and their feelings about the river so that the correlation coefficient between these two variables in the post-test increased (Table 4). The Keelung High School participants, who monitored a pristine area of the Keelung River during the monitoring section of the program, re-evaluated their original perceptions of the river's pollution and their feelings about the river became more positive. However the Sonsan High School participants' evaluations and feelings about the river did not change after they had visited a polluted part of the Keelung River (Table 3).

Familiarity with a particular environment is an effective predictor of preference for the environment (Medina, 1983) and an indicator of awareness of the

Table 4. Correlation Coefficient between Students' Evaluation of the River's Health and Their Feelings about the River

	Evaluation of river's health	
	Pre-test	Post-test
Feelings toward the river	0.69	0.85

environment. The baseline data showed that examinees were not familiar with the Keelung River before the program, although the two schools were located along the Keelung River. These findings were similar to Hsiao's results (Hsiao, 1991). His research showed that the general public did not think of natural water, i.e. a river or lake, when they were asked about water. The author thinks that, in the case of high school students, the overwhelming tensions of academic study do not often give them a chance to visit the Keelung or Tansui River. This implies that local people (including senior high school students) have lost a feeling of connection with rivers. These feelings are essential for stimulating them to take action.

Although they were not familiar with the Keelung River in the pre-test, they assessed it as polluted, dirty, and ugly. This phenomenon also occurred in surveys done by Hsiao (1991) and Hwang (1991). Their data show that the general public and vocational school students evaluated Taiwanese rivers in general as "seriously polluted" in spite of different levels of pollution in different rivers. These prevailing ideas that rivers are seriously polluted may cause people to feel powerless and block them from taking action, according to Bardwell's study (Bardwell, 1992).

These previous data proved that, by directly experiencing the river, learners have an opportunity to use their senses – hearing, seeing, touching and smelling – to build up salient and non-rejectable information on the studied river. The situation is supported by Fazio and Zanna's experiment (Fazio and Zanna, 1981) and Bem's theory (Bem, 1970). The benefit of direct, purposeful experiences, like the water monitoring activity, for developing awareness and sensitivity towards the environment has been noted (Engleson, 1985).

2. Students' Attitudes toward Saving the River

Null hypothesis 2 is rejected according to an ANOVA test, with 0.01 significance level. TREP significantly increases participants' feelings of empowerment toward saving the river. The mean differences between the pre- and post-tests of the experimental groups in Keelung High School and Sonsan High School were 0.73 and 1.06, respectively.

After the program, participants from both schools felt more empowered to save the Keelung River, as indicated by their scores on the statements, "the task will be successful," "I feel empowered to improve the river," "I have ideas about what to do," and "I can help." However, only Sonsan participants' feelings of responsibility for the task significantly increased after the program. The change in the Keelung participants' feelings of responsibility was on the statistical margin (Table 5). In addition, only the Keelung participants felt that saving the Keelung River was not as difficult as they had perceived before the program. This was perhaps because the river area they visited seemed relatively clean based on its appearance and the water quality data they obtained. This research found that the negative influence of perceived difficulty on empowerment was reduced by TREP (Table 6). Possibly, this was because TREP provided the knowledge and skills necessary to overcome the negative feelings of powerlessness.

With regard to students' attitudes toward saving the Keelung River, the baseline data show that students in these senior high schools did not feel empowered or responsible for undertaking the task, although most

Table 5. Pre-test and Post-test Comparison of the Two Schools in Terms of Attitudes Toward Saving the Keelung River

Name of school Dimensions	Mean		Difference between two tests	F value	P
	Pre-test	Post-test			
Keelung School					
Importance	6.46	6.40	-0.05	0.14	0.764
Difficulty	5.50	4.40	-1.10	19.26	0.000
Empowerment	4.41	5.15	0.73	23.38	0.000
Responsibility	5.05	5.32	0.28	4.82	0.03^{M}
Sonsan School					
Importance	6.58	6.65	0.07	0.20	0.659
Difficulty	5.89	5.66	-0.23	1.20	0.277
Empowerment	4.22	5.28	1.06	25.61	0.001
Responsibility	5.12	5.56	0.43	6.42	0.010

Note: Score is from 1 to 7.
M: Margin ($p<0.05$)

Table 6. Mean of Four Items in the Empowerment Dimension and the Correlation of Success and Empowerment with Difficulty in the Pre-test and Post-test

Items of Empowerment Dimension	Mean		Correlation coefficient with difficulty dimension	
	Pre-test	Post-test	Pre-test	Post-test
The task will be successful	5.20	5.95**	-0.15	-0.12
I feel empowered to do it	3.54	4.56**	-0.34	-0.10
I have ideas about how to help it	3.57	4.73**		
I can help in achieving the task	5.0	5.57**		
Perception of Difficulty	5.68	4.95***		

** the difference between pre- and post test meets a significance level of less than 0.001.

felt that saving the river was very important and urgent. Hwang's survey (Hwang, 1991) also showed that 65% of 2,794 surveyed vocational school students agreed with the statement, "I am a student, therefore what I can do for the environment is limited." Therefore there was a discrepancy between students' perceptions of the importance of saving the river and their feelings about doing it.

The case study on citizen action, as well as their own action-taking experience in the program may have increased students' feelings of empowerment and responsibility for saving the river. Bandura (1977) pointed out that people's feelings of self-efficacy will increase after studying a successful case and accomplishing tasks.

However, the author raised a concern about water monitoring activities in Taiwan. The research findings show that students' experience with the river strongly influenced their feelings about the river and their evaluation of the difficulty of saving the river. Generally, a negative feeling towards the river often prevents people from accessing or discussing the river.

The findings lead to the question "What constitutes a good site for students to do water monitoring?" According to the community problem solving approach, the water monitoring sites ought to be close to participants' schools or homes (community-based) so that teachers can link the river issues with students' lives and encourage them to follow up with action taking (problem solving) in their families, school or community. However, in Taiwan, the lower and middle reaches of most rivers, where most students live, are seriously polluted. If students visited the polluted parts, their perceptions of river pollution would increase. Therefore, if there is more than one opportunity to do water monitoring, it would be a good idea to visit an unpolluted part of the river in addition to the rivers near their schools or homes. Students can then build a sense of appreciation and respect for the rivers.

3. Students' Sense of Responsibility for Environmental Protection

Null hypothesis 3(i) is rejected according to an ANOVA test with 0.05 significance level. Null hypothesis 3(ii) is rejected by a paired t-test with 0.05 significance level. TREP significantly increases students' feelings of responsibility for school environmental protection. The mean difference between the pre- and post-test of the experimental group was 0.2. The mean difference between the control group and the experimental group after the program was 0.4.

Participants' attitudes toward who should be responsible for the school environment were examined according to four aspects of the process: providing ideas to initiate a task, planning, decision making, and funding. In terms of decision making and planning, participants significantly changed their attitudes after the program (Table 7). Before the program, they were neutral about who should be responsible for these tasks; after the program, they felt that students should have greater responsibility for them than the administration. With regard to providing ideas to initiate school environmental protection, the participants tended to attribute responsibility to the students both before and after the program. In the pre-test and post-test, the control and full participation group both thought that the school administration should provide more funding for school environmental protection than students.

In the pre-test, student attitudes tended to be neutral. They felt the administration and students should equally share responsibility for the school environment. Or, possibly, they had no particular feel-

Table 7. Examinees' Sense of Responsibility for School Environment in the Pre- and Post-test

Group	Mean		Difference between the two tests	Paired t	P
	Pre-test	Post-test			
Attitudes toward decision making					
Control classes	2.92	2.76	-0.17	-1.75	0.082
Full participants	2.93	3.28	0.32	2.66	0.009
Attitudes toward planning					
Control classes	2.79	2.70	-0.08	-0.82	0.415
Full participants	2.89	3.30	0.38	2.98	0.004
Attitudes toward responsibility for initiating					
Control classes	3.99	3.73	-0.27	-3.31	0.001
Full participants	4.08	4.14	0.05	0.47	0.638
Attitude toward funding					
Control classes	2.15	2.22	0.04	0.55	0.580
Full participants	2.23	2.28	0.04	0.33	0.744

Note: Score is from 1 to 5.

ings about it and their rating was influenced by the "middle-way philosophy" that is dominant in Chinese society.

The middle-way philosophy means maintaining balance and not going beyond society's limits. It would be good if students indeed strongly believed that the administration and students should equally share the responsibility. However, in real-life situations, people's attitudes often do not exactly hold to a "middle-way" position and tend to be non-neutral.

A bottom-up and public participation approach for environmental protection is usually promoted by social environmentalists. (Milbrath, 1989) This requires that people have very strong attitudes toward responsibility for initiation, planning, decision making, and funding of local environmental protection. The author feels that a democratic atmosphere in school – allowing students to make their own plan and finish it – may be a useful way for managing students' cleaning tasks in schools or communities and establishing a sense of their environmental responsibility. However, generally, school administrators are dominant and decide on a working plan for environmental tasks and mandate students to implement it. Students must follow this mandate an opportunity for decision-making or taking responsibility on their own.

4. Students' Intention to Take Environmental Actions

Null hypothesis 4(i) is rejected by an ANOVA test with 0.05 significance level. Null hypothesis 4(ii) is rejected by a paired t-test with 0.05 significance level. TREP significantly increases students' intentions to take actions. The mean difference between the pre- and post-test of the experimental group was 0.5. The mean difference between the control group and the experimental group after the program was 0.65.

Students were asked how likely it was that they would take each of the 15 environmental actions. According to the mean level of intention, the 15 actions were divided into three clusters by factor analysis: "personal behavior change," "advocacy and self-education," and "school environmental action". After the program, participants' intentions to take actions related to "advocacy and self-education" and "school environmental actions" significantly increased (Table 8). However, participants did not increase their intention to take "personal behavior change" approach, possibly because the pre-test scores were already quite high, 4.8 (The highest value is 6.0).

Chow's survey (Chow, 1992) also indicated that primary and secondary school teachers had greater intentions to change personal behavior than other options (teaching students about the environment in classes, persuading the whole school to protect the environment and participating in environmental activities out of school). In the U.S., Jordan's study (Jordan, Hungerford, & Tomera, 1986) involving American students showed that their knowledge of environmental action-taking was much more oriented toward an eco-management approach than any other approach both before and after his program. This may be because changing personal behavior (eco-management) relates more to common sense, is socially acceptable, simpler, less controversial, and requires less time and energy than the other actions. The author think these attitudes are supported by beliefs common in Chinese culture: that one's foremost concerns should

Table 8. Pre-test and Post-test Comparison of the Control Classes' and Full Participants' Intentions to Take Environmental Actions in the Three Clusters

	Mean			
	Control (169)		Full (104)	
Clusters	Pre-test	Post-test	Pre-test	Post-test
Personal behavior Advocacy	4.73	4.80	4.70	4.89
and learning	3.44	3.46	3.45	4.14**
School env. protection	3.45	3.43	3.74	4.27**

Notes: Scale is from 1 to 6.

Comparison between pre- and post-test used two-tailed, paired t-test with alpha=0.05.

** P<0.001

be about personal daily life and fulfilling one's duties. Beyond the individual and family levels, there are few feelings of responsibility for public affairs and little tendency to act for the public good.

Larson, Forrest, & Bostian (1981) argued that environmental actions taken in the household are not a good indicator of people's commitment to solve environmental problems. Personal behaviors are less expensive, more expedient and/or habitual than political and legal actions. Therefore, it is meaningful that TREP increased students' intention of taking actions related to persuasion and school environmental tasks. Actually, at the end of this program the students wrote letters and made posters to increase their schoolmates' concern for the rivers.

5. Students' Knowledge of Water Quality

Null hypothesis 5(i) is rejected by an ANOVA test with 0.05 significance level. Null hypothesis 5(ii) is rejected by a paired t-test with 0.05 significance level. TREP increases students' knowledge of water quality. The mean difference between the control and experimental group after the program was 0.06. The mean difference between the pre- and post-test of the experimental group was 0.06.

Null hypothesis 5(iii) is rejected by an ANOVA test with 0.05 significance level. Null hypothesis 5(iv) is rejected by a paired t test with 0.05 significance level. TREP increases students' feelings of confidence about this knowledge. The mean difference between the control and experimental group after the program was 0.31. The mean difference between the pre- and post-test of the experimental group was 0.30.

Students assessed the impacts of the twelve activities on river water quality as "positive," "negative," or "zero" (Appendix A). After the program, the participants' accuracy in answering these questions increased and was higher than that of the control classes (Table 9). Participants' confidence in their knowledge of water quality also increased and was higher than the control classes in the post-test (Table 10). After the program, the students' ability to correctly assess the impact of the twelve activities on overall river water quality, as well as their confidence in their answers, had increased. But the mean difference between the pre- and post-test was small because the students had been quite knowledgeable before the program (Table 9, 10). Talsma's evaluation (Talsma,

Table 9. The Mean Score of Water Quality Knowledge of Each Group in the Pre-test and Post-test and the Difference between Pre- and Post-test

Group	No.	Mean score[1]		Difference between pre and post-test	Paired t	P
		Pre-test	Post-test			
Control classes	170	0.82	0.82	0.00	0.05	0.957
Experimental classes	172	0.80	0.85	0.06	4.81	0.000
Non-participants	22	0.80	0.82	0.02	0.88	0.389
Partial participants	47	0.77	0.81	0.05	1.66	0.104
Full participants	103	0.82	0.88	0.06	5.15	0.000

[1] Mean score is between 0 and 1.

Table 10. The Mean Scores for Confidence in the Water Quality Knowledge of Each Group in Pre-test and Post-test and the Difference between Pre- and Post-test

Group	No.	Mean score[1]		Difference between pre- and post-	Paired t	P
		Pre-test	Post-test			
Control Classes	169	3.18	3.20	0.01	0.42	0.675
Experimental Classes	172	3.18	3.40	0.22	6.67	0.000
Non-participants	22	3.24	3.27	0.03	0.53	0.605
Partial participants	47	3.06	3.22	0.16	2.16	0.036
Full participants	103	3.22	3.51	0.30	7.00	0.000

[1] Four points scale covers from 1. very unsure, 2. unsure, 3. sure, 4. very sure.

1992) of the Rouge Project also found this to be the case.

However, students' accuracy in assessing the impacts of the three activities "fishing from the river bank," "using soap instead of detergent," and "removing mud from the river bottom" did not improve after the program (Table 11). Moreover, the mean scores for accuracy in assessing "fishing," "removing mud from river bottom," and "using soap instead of detergent" did not increase significantly and students' confidence for these three items was lower than their confidence for other items. This is not surprising, as the task of "removing mud from the river bottom" was not mentioned in the program. Also, the participants may have rated "fishing" as a negative impact because the third section of the program mentioned illegal fishing with poisons; students were also not very sure of their answers. Nearly half of the full participants assessed "using soap instead of detergent" incorrectly, possibly because students did not know the benefit of using soap, or because students answered the question without comparing detergent with soap and thought that soap was a pollutant. These results imply that TREP did not improve participants' water quality knowledge in certain aspects, yet tended to increase their confidence about their knowledge of water quality.

IV. Conclusion

The Tansui River Education Program is an innovation within Taiwanese formal education. During the program, students go out of school to monitor their rivers and take actions for the river (interdisciplinary characteristics and community problem solving approach). The research found TREP significantly increased participants' environmental

Table 11. Comparison of Full Participants' Pre-test and Post-test Mean Scores in Terms of Accuracy and Confidence

No.	Item	Accuracy		Confidence	
		pre-test	post-test	pre-test	post-test
8	acid rain	0.98	0.97	3.52	3.67*
3	replacing lawns with cement	0.95	0.99	3.37	3.62***
1	overuse of fertilizer	0.93	0.99	3.48	3.67**
4	discharge from septic tank	0.90	0.98*	3.50	3.70**
9	garbage on the streets	0.89	0.99**	3.52	3.68*
5	changing woodland into golf course	0.88	0.96*	3.35	3.56**
7	fishing from river bank	0.82	0.77	2.95	3.29***
10	hot water discharged from factory	0.80	0.90**	3.23	3.54***
6	digging up sand along river bank	0.77	0.89**	3.10	3.47***
11	building roads over the river	0.75	0.89***	3.06	3.42***
12	removing mud from river bottom	0.63	0.64	2.90	3.29***
2	using soap instead of detergent	0.51	0.58	2.68	3.22***

Note: A paired t-test with 0.05 significant level was used in comparing the pre- and post-test scores, which were independent.
* $p<0.05$
** $p<0.01$
*** $p<0.001$

awareness, knowledge, attitudes, and empowerment. In addition, participating students and teachers were in favor of it. Therefore, the author suggests this type of education program should be promoted with further research to compare it with other teaching approaches.

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Appendix

Questionnaire

A. A couple of paired adjectives and short sentences are listed below. Please mark the level of each in "saving the Keelung River".

The Keelung River

I strongly agree with the left description	3	2	1	0	1	2	3	I strongly agree with the right description
I know it vaguely								I know it well
I am unfamiliar with the river								I'm familiar with the river
It is dirty								It is clean
It is turbid								It is transparent
It is beautiful								It is ugly
I dislike it								I like it
I feel sad about it								I feel happy about it
I am worried about it								I am content with it

Saving the Keelung River

I strongly agree with the left description	3	2	1	0	1	2	3	I strongly agree with the right description
It is necessary								It is unnecessary
It is urgent								It is not urgent
It is difficult								It is easy
Simple task								Complex task
Efforts to save it would be unsuccessful								Efforts to save it would no be successful
It's government's responsibility								It's the citizens' responsibility
I feel helpless								I feel empowered
I don't know what I can do								I have ideas about what I can do.
I can help								I can not help
The task is a mission for me								It is a trouble for me
My life will change for it								My life will not change for it

Effects of the River Program on Students

B 1. The following activities may affect the water quality of rivers in different ways — by improving or degrading or not affecting the water quality. Please circle the effect of each activity in column A.
"+"= improves water quality or reduces degradation of water quality
"-" = degrades or worsens water quality
"o"= does not affect water quality

B 2. At the same time, how confident do you feel about your knowledge when you answer each question? Please indicate the extent to which you are confident in answering each question in column B.

Activities	column A impact on water quality			column B degree of confidence			
	good	none	bad	very unsure	unsure	sure	very sure
1. Overuse of fertilizer in the farmers' fields	+	0	-	1	2	3	4
2. Using soap instead of detergent for laundry	+	0	-	1	2	3	4
3. Changing lawns into cement along the river	+	0	-	1	2	3	4
4. Discharge from septic tank	+	0	-	1	2	3	4
5. Changing woodlands into golf courses	+	0	-	1	2	3	4
6. Digging up sand along the river bank	+	0	-	1	2	3	4
7. Fishing from the river bank	+	0	-	1	2	3	4
8. Acid rain	+	0	-	1	2	3	4
9. Garbage on the streets	+	0	-	1	2	3	4
10. Hot water discharged from factories	+	0	-	1	2	3	4
11. Building roads over the river	+	0	-	1	2	3	4
12. Dredging the mud from river bottom	+	0	-	1	2	3	4

C. The following are paired statements about who has responsibility for school environmental protection, the school administration or students. After you consider the ideal and actual situation (personal factors, academic work load, school administration and society), who do you think should take charge of school environmental protection? Please indicate your opinion about each pair of statements by circling a number.
1=strongly agree left   2=agree left   3=neutral
4=agree right   5=strongly agree right

1. Students should wait for directions from the administration then take action.	1	2	3	4	5	Students should initiate school environmental protection (e.g. providing ideas on recycling).
2. The direction of school environmental protection should be decided by the administration (e.g. whether or not the school should recycle)	1	2	3	4	5	The direction of school environmental protection should be decided by student
3. School environmental protection tasks should beplanned by the administration (e.g. how to do recycling tasks)	1	2	3	4	5	School environmental protection tasks should be planned by students.
4. School environmental protection should be funded by the administration.	1	2	3	4	5	School environmental protection should be funded by students

D 1. The following are some environmental actions or activities. How likely do you think it is that you would take these actions or participate in these activities? Please circle the number that is closest to your opinion.
1=very unlikely   2=unlikely   3=somewhat unlikely
4=somewhat likely   5=likely   6=very likely

1. Telling your family to reduce use of detergents	1	2	3	4	5	6
2. Not throwing away bruised vegetables and fruits	1	2	3	4	5	6
3. Informing the school about dripping faucets	1	2	3	4	5	6
4. Watching TV programs about the environment	1	2	3	4	5	6
5. Advising neighbors not to dump illegally	1	2	3	4	5	6
6. Writing an article about the environment to persuade the public	1	2	3	4	5	6

7. Collecting articles about the environment	1	2	3	4	5	6
8. Writing a letter to the EPA for law enforcement	1	2	3	4	5	6
9. Calling the local EPA about polluting behavior	1	2	3	4	5	6
10. Making a poster to increase schoolmates' environmental awareness	1	2	3	4	5	6
11. Turning off lights which are not needed	1	2	3	4	5	6
12. Cleaning drains in the school	1	2	3	4	5	6
13. Investigating where school waste water flows	1	2	3	4	5	6
14. Collecting and storing chemicals used in the school's lab	1	2	3	4	5	6
15. Being a member of an environmental group	1	2	3	4	5	6

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淡水河教育計劃對高中生的環境態度與知識之影響

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摘要

本研究主要目的在設計並且評量一個適合中學生的淡水河河川環境教育計劃。此河川教育計劃包括五個單元：(1)我的淡水河經驗。(2)淡火河面面觀。(3)水質監測。(5)個案研究。(5)環境行動演練。位於淡水河支流—基隆上游、下游的基隆高中、松山高中二年級共四班於星期假日參與此教育活動，當作實驗組。另選這兩校，修課組別和學業成績與實驗組相近的四個班級作對照組，該組並無參與任何的活動。在活動前後一星期，兩組分別進行前測與後測，以了解此淡水河河川教育計劃對於參與者的認知、態度與知識的影響。前後測比較與實驗組對照組比較結果顯示，此教育計劃能(1)影著增加他們對於基隆河的認知。(2)顯著增加參與者拯救河川的有力感。(3)顯著增加他們採取宣導和參與學校環境保護工作的行動意向。(4)顯著增加他們在參與學校環境工作的規劃和做決定的責任感。E顯著增加學生有關河川水質知識的正確度與自信度。基於研究結果，筆者建議教育部應該考慮類似的河川教育計劃放入課程中。

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Taiwanese Elementary Students' Perceptions of Dinosaurs

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ABSTRACT

In a child's mind, dinosaurs are creatures with mystical charm. Every major natural history museum in the world has a rich dinosaur collection and fascinating dinosaur galleries which are very popular among children. Although little information on dinosaurs exists in Taiwanese k-12 textbooks, children in Taiwan obtain related information through various informal channels including science museums.

This study conducted by curators at the National Museum of Natural Science(NMNS) mainly investigated the perceptions of Taiwanese children of dinosaurs. A questionnaire composed of multiplechoice and open-ended questions was developed as an instrument for data collection. A total of 651 children belonging to three age groups (grades 2, 4 and 6) were randomly selected from 5 elementary schools in the Taichung Area and asked to answer the questionnaire. Qualitative data was collected by interviewing both children who answered the questionnaire (N=24) and who visited the dinosaur gallery (N=12). The results showed that there was a significant difference in preference towards dinosaurs between boys and girls. This study also reports on the causes of children's perceptions, children's informational sources, and their understanding of the reasons for the extinction of dinosaurs. The findings are not only provided as a reference for science educators, but will also help NMNS understand what young visitors think and give it an empirical basis for improving the dinosaur gallery.

Key Words: elementary students, dinosaurs, perceptions, Taiwan

I. Introduction

In a child's mind, dinosaurs are creatures with mystical charm. Every major natural history museum in the world has a rich dinosaur collection and fascinating dinosaur galleries which are very popular among children. Thus the dinosaur gallery at the National Museum of Natural Science (NMNS) in Taiwan has been a big attraction for school children since it opened to the public in 1988.

The dinosaurs constitute a biological population with great diversity in size, shape and feeding habits. Their evolution and controversial processes of extinction can provide a suitable framework for children to understand the scale, time sequence and chronological relation of life on Earth. This can also provide a knowledge base helping children to understand earth's biological diversity, the impact of their environment on living organisms, the causes of extinction and the mechanisms of competition. If approached correctly, the study of dinosaurs could become one of the best topics for introducing children to the fasinating world of natural history.

Since 1841, the year the word "dinosaur" was first coined by British paleontologist Richard Owen, numerous publications introducing dinosaur issues with both scholar and popular orientations have been published. Besides publications relating scientists' investigations of dinosaurs (British Natural History Museum, 1979; Lambert & the Diagram Group, 1990; Norman, 1985, 1991; Benton, 1992), much material about dinosaurs in the form of writings, films, and games etc. have been created incorporating the author's own imagination. The most notable instance of this in the recent years is the film Jurassic Park, which was directed by Steven Spielberg based on a fictitious story written by the American author Michael Crichton. Such films have not only attracted big audiences in the theater, but have also spurred the prevailing interest in dinosaur issues.

The reasons for such public interest in a group of species extinct for 65 million years has always been an interesting question for biologists, educators, psychologists, and sociologists. As museum curators, Gardom & Milner (1993) tried to provide explanations for this phenomenon from three perspectives:

(1) First, dinosaurs were such special animals that people somehow look at them as if they were monsters described in legends and myths. Such a belief fills people with feelings such as excitment, astonishment and enchantment.

(2) Second, since dinosaurs are all extinct, people do not need to be concerned about what people might have done to hurt these species. This lessens people's guilt while dealing with dinosaur issues.

(3) Finally, because knowledge about dinosaurs is still limited, novel findings are emerging all the time. Therefore, the conceptual framework about dinosaurs created by the scientific community often changes when new materials are added. Such a situation provides amateurs a broad scope for satisfying their desire to investigate.

Science educators have investigated children's misconceptions concerning various aspects of natural phenomena in both Taiwan and other countries (Gil & Carrascosa, 1990; Rowell, Dawson, & Lyndon, 1990; Wu, 1993). In the life sciences, Taiwanese researchers have investigated children's conceptions concerning ecology, plants, life and so on (Yu, 1995; Hsiung, Chang, & Hsiung, 1996; Dai, 1995; Huang, 1996). However, none has done research on conceptions of paleontology. In the United States, Chi & Koeske (1983) selected dinosaurs as a vehicle to study how child's memory performance was affected by their knowledge. In Barba's study (Barba, 1995), she found that children had developed their concepts of dinosaurs at a tacit level by experiencing models, pictures, and films. Even though young children had difficulty verbalizing their conceptual understandings of ancient fauna, they were able to classify representations of fauna as being Mesozoic or non-Mesozoic species with high degree of accuracy. As children matured and/or had more encounters with dinosaur-related concepts, they were able to verbalize more geological-time-related explanations of ancient life. Barba concluded that her findings supported Polyani's Theory of Tacit Knowledge in that children's conceptual understanding was built first at a tacit level and later developed at an explicit level.

As a part of the informal learning system, science museums have put much effort into studying their visitors (Finson & Enochs, 1987; Dierking & Falk, 1994; Hood & Roberts, 1994; Diamond, 1994; Boisvert & Slez, 1994; Lewenstein, 1993; Screven, 1993), the design of exhibits (Bernfeld, 1993), and the effect of public services (Silverman, 1993). Being a focal exhibit area in the museum, dinosaurs can serve as a "hot" issue for curators of NMNS to learn about the interactions between visitors and exhibits, and about ways to facilitate such interactions.

Although dinosaur fossils have never been discovered in Taiwan, and there is no topic introducing dinosaurs in Taiwanese k-12 textbooks, through the channels of informal learning such as mass media, scientific publications, dinosaur exhibits and peer communication, Taiwanese children have been able to construct a knowledge framework about dinosaurs. According to Solomon (1987), social influences play important roles in children's understanding of scientific issues. Based on this premise, it is especially interesting for science educators to investigate what Taiwanese children's conceptual frameworks of dinosaurs are like and how they blend information from a variety of sources. The results of this study could be used to help NMNS to understand what young visitors think about such of creatures and provide empirical evidence for improving dinosaur exhibits.

II. Research Questions

This study mainly focuses on answering the following research questions:

(1) What is the degree of preference of Taiwanese elementary students for dinosaurs?

(2) What are the most popular and unpopular dinosaurs according to Taiwanese elementary students?

(3) What is(are) the main source(s) of information about dinosaurs for elementary students in Taiwan?

(4) What are Taiwanese elementary students' perceptions of the existence and the features of dinosaurs?

(5) What reasons for the extinction of the dinosaurs are known to elementary students in Taiwan?

(6) What factors play roles in forming Taiwanese children's perceptions of dinosaurs?

III. Design and Procedure

In order to achieve the objectives of this study, a questionnaire composed of multiple-choice and open-ended questions and including topics such as the existence of dinosaurs, their size, reasons for their extinction, and the relationship between dinosaurs and man was developed. The main topics in the questionnaire were based on research questions proposed, discussed and agreed on by the 7 members of the study group. A prototype questionnaire was distributed to a small group of students in a pilot study. The comments from both the children and their teachers were used as feedback for refining the way the questions were written and the criteria for choosing appropriate questions.

Five elementary schools in the Taichung area were selected as the target schools for this study. In these schools, 2nd, 4th, and 6th grade classes were randomly selected to answer the questionnaire. The questionnaires were distributed to the sampled classes with assistance from their teachers. Before students gave their answers, the teachers described the purpose of the questionnaire and how to fill it out. For the 2nd-grade students, their teachers read and explained the meaning of each question to make sure the students understood what the questions asked. The time allotted for completing the questionnaire was 30 to 40 minutes. A total of 651 children from 15 classes belonging to three age groups answered the questionnaire (Table 1). Among them, 85% respondents mentioned they had visited NMNS during the last two years.

To obtain more in-depth information, children who gave relatively correct responses for either the multiple-choice or open-ended questions were selected for a further interview. A total of 24(14 male, 10 female) students including 10, 8, and 6 students from the 6th, 4th, and 2nd grade respectively participated in the interview process. In addition, some informal interviews with respondents were also held with assistance from the elementary school teachers. Furthermore, in order to obtain direct information for the purpose of exhibit improvement, a small number of elementary students ($N=12$) were interviewed while they were visiting the dinosaur gallery of NMNS.

Quantitative data from the questionnaires was analyzed by statistical methods such as frequency analysis and the chi-square test. Data from the interviews was analyzed by the analytic-induction method. Qualitative data from various interviewees was first reviewed and then classified into primitive categories by individual researchers. The primitive categories then served as a basis for the researchers' further discussion for the purpose of achieving consensus on the categorization. Based on these results, assertive statements were then generated. In presenting the findings, selected statements from interviewees were directly quoted as supporting evidence.

Table 1. Demographic Data of the Respondents

Variables	*N* (%)	Variables	*N* (%)
School		Sex	
A	142 (21.8)	Male	337 (51.8)
B	118 (18.1)	Female	314 (48.2)
C	121 (18.6)	Grade Level	
D	150 (23.0)	2nd	221 (33.9)
E	120 (18.4)	4th	216 (33.2)
		6th	214 (32.9)

Note: *N*=Number of respondents

IV. Limitations of the Study

The quantitative data shown in this study was mainly used as the basis for selecting students for interviews. The statistical results generated in this study were not expected to totally represent other regions in Taiwan or Taiwan as a whole. Compared with the results from the random sampling procedure, the significance of the qualitative information in this study should be examined carefully, although a sampling process and statistical methods were also utilized.

V. Findings

1. The Majority of Students Expressed a High Level of Preference for Dinosaurs

Nearly half of sampled elementary students (49.3%) expressed preference for dinosaurs (Table 2). Less than 10% of students dislike or strongly dislike dinosaurs. Significant differences also exist between different age groups ($X^2=36.4$, $df=10$, $P<0.001$). More 4th graders are fond of dinosaurs than 2nd and 6th graders. If gender is considered, boys show greater preference for dinosaurs than girls ($X^2=56.9$, $df=5$, $P<0.001$). Boys are likely to express their attitudes about dinosaurs agressively; however, girls are relatively more conservative. In the interview, a girl who represented the typical feminine view said:

> The dinosaurs are boys' stuff.

It seems that dinosaurs are included in the same category as things like monsters, machine guns, and other science-based objects, which boys are much more interested in.

2. The Most Popular and Unpopular Dinosaurs Have a High Degree of Overlap

The most popular and unpopular species of di-

Table 2. The Extent of Preference for Dinosaurs of Sampled Elementary Students Based on the Different Variables

Variables	1 *N*(%)	2	3	4	5	0
Grade						
2	73(33.0)	34(15.4)	11(5.0)	12(5.4)	74(33.5)	17(7.7)
4	85(39.4)	35(16.2)	8(3.7)	2(0.9)	76(35.2)	10(4.6)
6	47(22.0)	47(22.0)	13(6.1)	9(4.3)	82(38.3)	16(7.5)
			$X^2=36.4$, $df=10$, $^{***}P<0.001$			
Gender						
Male	146(43.3)	58(17.2)	8(2.4)	12(3.6)	94(27.9)	19(5.6)
Female	59(18.8)	58(18.5)	24(7.7)	11(3.5)	137(43.8)	24(7.6)
			$X^2=56.9$, $df=5$, $^{***}P<0.001$			
Total	205(31.5)	116(17.8)	32(4.9)	23(3.5)	232(35.6)	43(6.6)

Notes: 1=Strongly Like, 2=Like, 3=Dislike, 4=Strongly Dislike, 5=Like Some; Dislike Others, 0=No Response
N=Number of respondents

Table 3. The Most Popular Species of Dinosaurs Named by Elementary Students

Rank	Species	Frequency
1	*Apatosaurus*	143
2	*Triceratops*	96
3	*Tyrannosaurus*	73
4	*Stegosaurus*	43
5	*Brachiosaurus*	36
6	*Pterosaur**	24
7	*Tanystropheus*	16
8	Flying Dragons	8
9	*Deinonychosaurs*	7
10	*Plesiosaurus**	6
11	Bubble Dinosaurs	5
12	*Deinonychosaurus*	5
13	Baby Dinosaurs	3
14	Plant-eating Dinosaurs	3
15	*Allosaurus*	3
16	*Ichthyosaurs**	3

* indicates species easily mis-recognized as a dinosaur.

Table 4. The Most Unpopular Species of Dinosaurs Named by Elementary Students

Rank	Species	Frequency
1	*Tyrannosaurus rex*	218
2	*Triceratops*	14
3	*Stegosaurus*	9
4	*Oviraptor*	8
5	*Pterosaur**	8
6	*Deinonychosaurus*	5
7	*Allosaurus*	5
8	*Apatosaurus*	5
9	Meat-eating Dinosaurs	3

* indicates species easily mis-recognized as a dinosaur.

nosaurs named by children are also reported in this study (Tables 3 and 4). *Apatosaurus*, *Triceratops*, and *Tyrannosaurus* are regarded as the top three most popular dinosaurs by sampled elementary students in this study. About 22% of students (*N*=143) who answered the questionnaire expressed a preference for *Apatosaurus*. The reasons they gave such an answer included: its genial character (*N*=61), herbivorous habit (*N*=36), huge body size (*N*=26), wouldn't eat humans (*N*=26) and cute appearence (*N*=25), etc. The cute appearance of *Triceratops*, especially the horns on its head, is the major reason it attracts students. In summary, the reasons mentioned by the respondents can be categorized as (1) the features, and (2) the nature of the dinosaurs. Some reasons also reflected respondents' own personality. For instance, an overweight male 4th grader said:

> I like *Apatosaurus* because I also have a fat body.

A 4th-grade girl who had strongly expressed her preference for dinosaurs in general mentioned that *Apatosaurus* was her favorite species because of its genial nature:

> Although *Apatosaurus* looks huge and strong, however it is genial and will not attack other species. I feel its character is just like mine. I like herbivorous species of dinosaurs because they maintain a peaceful atmosphere.

Both students highlighted the features of the dinosaurs, from either a morphological or psychological perspective, to justify their feelings. In the case of *Tyrannosaurus*, although it ranked third place on the list of popular species, the reasons were quite different from those for plant-eating dinosaurs. Students indicated that its strong body and fierce nature attracted them. A male respondent in 6th grade expressed that *Tyrannosaurus* was his idol. He said:

> I like strong figures. *Tyrannosaurus* represents such a figure in my mind. Its mighty power attracts me. I also like its dominating nature. I look at *Tyrannosaurus* as a model for me to emulate.

Interestingly, *Tyrannosaurus* was also named the most unpopular species of dinosaur by 218 students because its potentially human-eating and carnivorous habits. The following response from a female 6th grader represents the typical reasoning behind such an opinion:

> I don't like *Tyrannosaurus*. It was fierce and likely to mistreat other animals. *Tyrannosaurus* even used its powerful teeth and claws to catch and beat the peaceful species. Lots of animals were killed by it. I don't like the violence. That's why I don't like *Tyrannosaurus*, either.

The number of students (N=218) who named *Tyrannosaurus* as the most unpopular is greater than for other species, for instance *Triceratops* (N=14), *Stegosaurus* (N=9), and *Oviraptor* (N=8), by a extremely large margin.

From the species listed by the students, we also find some kinds of animals which do not belong among dinosaurs. These species such as *Ichthyosaurs*, *Plesiosaurus*, and *Pterosaur* are usually misrecognized as dinosaurs because of their similar appearance. How children judge whether an animal is a dinosaur or not will be discussed in the following section.

Some dinosaurs created by designers such as bubble dinosaurs and baby dinosaurs were also listed by respondents. This fact tells us children are not confined by the scientific system in expressing their opinions about such kinds of questions.

From the species names of the most popular and unpopular dinosaurs listed by children, we may infer that some species are more familiar to Taiwanese children. These "dinosaur stars" include *Apatosaurus*, *Triceratops*, *Tyrannosaurus*, *Stegosaurus*, *Brachiosaurus*, etc. Because of children's existing knowledge about dinosaurs, the species shown in Tables 3 and 4 have a high degree of overlap.

3. One of the Reasons Children Are Fond of the Dinosaurs Is Their Diversity in Features and Habits

As stated above, most students determined their favorite dinosaurs according to the nature and the habit of the dinosaurs. While interviewed, some children expressed they were curious about the dinosaurs because of their various appearances and habits. A 6th grader said:

> I was in touch with this subject since I was in kindergarten. At that time, I heard others talking about dinosaurs. I felt that dinosaurs must be interesting and attractive. Thus I began to read books introducing dinosaurs. The more information I got, the more I liked dinosaurs.

When asked why he liked the dinosaurs so much, he replied:

> Because the dinosaurs are a group of animals. This group is composed of different species of animals. I found this very interesting.

When the interviewer asked about dinosaurs' huge body size and tall figure, the student replied:

> When I first studied dinosaurs, I didn't pay much attention to their sizes. This is not the major reason I like them. I think the fact that dinosaurs were animals existing in an ancient period aroused my curiosity. I love novel things which I have never seen before, such as monsters in strange worlds.

According to his words, it was the life history and biodiversity of the dinosaurs, not the image of their strong and tall bodies, that attracted his interest. Moreover, another 6th-grade student who had expressed in-depth thought about the dinosaurs in her interview also described the diversity of dinosaurs in terms of skin color, food sources, habitats, etc. to illustrate the fascination of the dinosaur group. In particular, she mentioned the value of dinosaurs in helping her learn the concept of biodiversity through comparison:

> By examining the species in the dinosaur group, I found they not only had similar characteristics to each other, but also the specific features individual species. From such examinations, I begin to realize that the dinosaurs were an interesting group that could help me to understand the similarity and diversity of biological species.

A 4th grader also emphasized a similar point:

> Some dinosaurs were tall; others were tiny. They were diverse in body size and height. I always thought that the larger means stronger before, however, after I learned some information about the dinosaurs, I began to realize that some small ones could defeat the bigger ones. After that I felt that dinosaurs not only gave me a lot of new information, but also let me observe nature from the other side.

This child studied dinosaurs in terms of their interactions and the diversity between species. Furthermore, she also began to understand the concept of competition by means of special examples. Although dinosaurs are usually described as huge animals, according to the interviews, some students showed they understand dinosaurs are a diverse group. In conclusion, interesting features and mysterious legends are the major motivatives for childern to learn about dinosaurs.

4. Most Students Judged Dinosaurs Superficially by Their Appearance, Not in a Systematic and Scientific Manner

Although children could describe the specific features of dinosaur that were familiar to them, they usually could not illustrate common features that define the whole dinosaur population. Some similar creatures such as *Ichthyosaurs*, *Plesiosaurus*, *Pterosaur*, and *Dimetrodon* were usually mistakenly regarded as dinosaurs. When asked what are dinosaurs' common features, most of students answered "I don't know" without any hesitation. They usually emphasized dinosaurs' diverse appearance and habits, but none of them could provide answers based on scientific definitions. Some children even misinterpreted dinosaurs as follows:

> Most dinosaurs lived on the land; some inhabited in the water; some could fly across the sky.

According to this description, some flying and marine reptiles existing in the age of the dinosaurs were apparently included in the "dinosaur family." However, according to children's answers, only certain flying and marine reptiles were categorized as dinosaurs. After the species most frequently proposed by children were checked, we found that species often introduced to children along with the dinosaurs-such as *Ichthyosaurs*, *Plesiosaurus*, *Pterosaur*, and *Dimetrodon*-were most commonly the subject of such misunderstandings. In addition, the morphology of dinosaurs has an effect on children's judgements, too. Children usually judge if a animal is a species of dinosaur roughly according to its appearance. Few students paid much attention to accurate scientific ways of defining dinosaurs.

5. What Factors Play Roles in Causing Misconceptions about Dinosaurs?

A. Translated Terms Make Children Mistakenly Consider Some Species as Dinosaurs.

In Chinese, dinosaurs are translated as [恐龍] from the word's meaning in English. However, in traditional Chinese legends there is also an artificial animal species called the dragon [龍]. Every species in the group of dinosaurs has a common name with the Chinese Character [龍]-dragon. However, few children are confused by the relationship between dinosaurs and the traditional Chinese dragon. When asked if a Chinese dragon was a dinosaur while being shown illustrations, only 10.4% of the respondents though it was a kind of dinosaur and nearly 79% of the respondents stated it was not. However, 10.4% of the students had no idea about this.

Table 5 shows both the English and Chinese names for some prominent species. No matter if they are dinosaurs or other reptiles, all of the last characters for the species shown in this table are [龍]. Not only the character [龍], but also their similarity in the appearance make students include them in the dinosaur group.

B. Although Descriptions in the Texts of Labels in the Dinosaur Gallery Provide Students Abundant Information about Dinosaurs, Some Misconceptions Appeared in Some Students' Minds during the Process of Informational Processing

Table 6 shows children's views about the size of dinosaurs. 50% of the elementary students regarded

Table 5. English and Chinese Names of Some Typical Dinosaurs and Dinosaur-like Reptiles

English Name	Chinese Name	Dinosaur or not
Apatosaurus	迷惑龍	Yes
Triceratops	三角龍	Yes
Tyrannosaurus	暴龍	Yes
Stegosaurus	劍龍	Yes
Pterosaur	翼龍	No
Plesiosaurus	長頸龍	No
Ichthyosaurs	魚龍	No
Dimetrodon	長棘龍	No

Table 6. How Large Were the Largest and Smallest Dinosaurs?

Item	Frequency	Percentage (%)
How large		
Elephant	36	5.5
A Classroom	10	1.5
2- to 3-Story Building	100	15.4
Lower than a 10-story Building	114	17.5
Taller than a 10-story Building	331	50.8
Don't Know	60	9.2
How small		
Rhinoceros	225	34.6
Pig	70	10.8
Chicken	112	17.2
Rat	148	22.7
Smaller than a Rat	42	6.5
Don't Know	54	8.3

the largest dinosaur as "taller than a ten-story building". Over 30% of respondents thought the largest dinosaur was between 2- to 10-story building. Few students give the answers such as "classroom-" or "elephant-size". On the other hand, the results for the size of the smallest dinosaurs are more diverse than for the size of the largest dinosaurs. Many students chose rhinoceros-size (34.6%) and rat-size (22.7%). Only 112(17.2%) students selected the correct answer – chicken-size. From students' perceptions about their sizes, we might conclude that dinosaurs are regarded as relatively large-sized animals.

When asked the reason for choosing "rat-size" as the answer in the interview, a male 6th grader who has visited the dinosaur gallery of NMNS several times stated:

> I have read the text on the labels in the dinosaur gallery. I am sure the smallest dinosaur is called *Compsognathus*. The text mentioned that *Compsognathus* is also known as *Mussaurus* which means rat-like dinosaur. That's why I am sure the size of the smallest dinosaur is just like a rat.

According to his statement, although he answered correctly about the smallest dinosaur, he was misled by the Chinese translation of *Mussaurus*–[鼠龍]–which means rat-like dinosaur.

On the other hand, in another case although a student chose the right answer for the size of the smallest dinosaur, he did not name the right species. He said:

> The smallest dinosaurs were like chickens. Their name was *Gallimimus* (chicken-like dinosaur).

In Chinese, *Gallimimus* is directly translated as [似雞龍] (chicken-like dinosaur). Such a translation shown in the exhibit text was supposed to transmit the message that *Gallimimus* looked like a chicken. However, some children were led to believe that the size of *Gallimimus* was similar to that of a chicken. Although *Compsognathus* and *Gallimimus* are nearby exhibits in the dinosaur gallery of the NMNS, the texts on their labels easily cause visitors to become confused and combine the information together.

In conclusion, those students who acquired more information in the dinosaur gallery of the science museum may be assumed to be students who study hard and are active learners. Students had to be familiar with the basic terminology used in the exhibit hall before they could make such mistakes. In case of the interviewees mentioned above, their teachers commented that these students had strong motivation to learn new things. However, it seems that for such students the components which form the different concepts were reorganized and disconnected before the complete information was firmly fixed into their long-term memory.

C. Some of Children's Misconceptions about Dinosaurs Originate from the Blending Information from the Mass Media with Their Own Imaginations

Most students agreed that dinosaurs appeared before human beings were on earth (N=513, 78.8%). However, 5.8% of elementary students thought man appeared earlier; nearly 10% of respondents said dinosaurs and man appeared during the same period (Table 7). Many students knew that dinosaurs were animals living on this planet long before human beings appeared. For instance, a 4th-grade student who used relatively more scientific terms in his interview than other students stated as follows:

> The dinosaurs were extinct in the Cretaceous. After that, man began to occupy the earth. So they did not overlap

Table 7. Who Appeared on Earth First? Dinosaurs or Man?

Item	Grade level			
	Total: N(%)	2	4	6
Man	38 (5.8)	6 (2.7)	12 (5.6)	20 (9.3)
Dinosaurs	513 (78.8)	181 (81.9)	166 (76.9)	166 (77.6)
Contemporaneous	59 (9.1)	16 (7.2)	24 (11.1)	19 (8.9)
Don't Know	41 (6.3)	18 (8.1)	14 (6.5)	9 (4.2)

X^2=13.5, df=6, $^*P<0.05$

Note: N=Number of respondents

> with each other.

When asked how long was this gap, the student said:

> About ten thousand years.

Although he knew the Cretaceous was an ancient period of time, he did not realize how long ago this period was. In his point of view, ten thousand years represented a period long enough to be the interval between the first emergence of humans and the end of the dinosaur era. Judging from his description, this student might understand the interval was not short, but was not certain about its exact length. It seemed that his answer was merely based on a surmise from his own limited information.

It is interesting that 46% of elementary students mentioned that ancient man had seen dinosaurs (Table 8). Although most children put the appearance of man and the dinosaurs in order correctly, it seems that some thought that the dinosaurs and man existed contemporaneously on earth for a period of time.

A male 2nd grader narrated a story that he had read from a book:

> ..... Some ancient people were not afraid of dinosaur attacks. They bravely fought with dinosaurs. They used tools made by themselves to shoot the dinosaurs. However, the men could not withstand the continuous assaults from the dinosaurs. They were eventually beaten. Since then, men began to fear and ran away from dinosaurs.

Other students also mentioned that they had seen man and dinosaurs appearing contemporaneously in the same cartoon or picture. The story generally depicted them fighting with each other. For instance, a first-grade student told the interviewer that he had watched *Tyrannosaurus* chasing people in the film Jurrasic Park while he was viewing the exhibit showing the attempt of *Tyrannosaurus* to catch *Triceratops*. Even from simulation games on computers, some students saw people and dinosaurs on the same screen. Men and dinosaurs are also found contemporaneously in books and drawings. All of these are usually fabulous stories. However, some students, especially lower graders, regarded the narratives in films, cartoons and pictures as real stories and adopted these as an element of their perceptions about dinosaurs.

Table 8. Did Ancient Man See the Dinosaurs?

Item	*N*	(%)
Yes	301	46.5
No	236	36.5
Don't Know	110	17.0

Note: *N*=Number of respondents

6. Major Sources of Information about Dinosaurs Changed Gradually from Lower to Higher Graders

According to the survey, grade is a factor influencing the source of elementary students' knowledge about dinosaurs (X^2=35.3, *df*=8, *p*<0.001). Over 60% of respondents mentioned that the science museum was a major source for acquiring information about dinosaurs (Table 9). Other sources include movies and television (16.2%, *N*=106), newspapers/books/magazines (14.8%, *N*=96), and discussions with other people (3.6%, *N*=23). More 4th and 6th graders learned about dinosaurs from newspapers/books/magazines (17.6% and 18.5%) than 2nd graders (8.1%). On the other hand, more 2nd graders (70.6%) regarded the science museum as a major informational source about dinosaurs than students in the other two grades. It seems that students in the higher grades obtain information from more diverse sources than lower graders, and channels other than the science museum become more important for their informational acquisition. While gender does not have a significant effect on the source of knowledge about dinosaurs (X^2=9.1, *df*=4, *p*>0.05), more girls learned such information from the science museum than boys. Among male students, the older the students the more they mentioned books and

Table 9. Major Sources of Knowledge about the Dinosaurs for Elementary Students

Variable	1 *N*(%)	2	3	4	0
Grade					
2	18(8.1)	32(14.5)	156(70.6)	9(4.1)	6(2.7)
4	38(17.6)	31(14.5)	141(65.3)	5(2.3)	1(0.3)
6	40(18.5)	43(19.9)	119(55.1)	9(4.2)	3(1.3)
	X^2=35.3, *df*=8, ****P*<0.001				
Gender					
Male	63(18.7)	56(16.6)	202(59.9)	12(3.6)	4(1.2)
Female	33(10.6)	50(16.0)	213(68.3)	11(3.5)	5(1.6)
	X^2=9.1, *df*=4, *P*>0.05				
Total	96(14.8)	106(16.2)	416(63.8)	23(3.6)	10(1.6)

Notes: 1=Newspapers/books/magazines, 2=Television or movies, 3=Science museum, 4=Communication with other persons, 0=No response; *N*=Number of respondents

Table 10. Major Sources of Knowledge about the Dinosaurs for Male Elementary Students

Source	Grade 2 *N* (%)	4 *N* (%)	6 *N* (%)	Total
Books, etc.	12(10.4)	23(20.3)	28(25.7)	63
Films	18(15.7)	16(14.2)	22(20.2)	56
Science Museum	79(6.9)	70(61.9)	53(48.6)	202
Other Persons	4(3.3)	4(3.6)	4(3.7)	12
No Response	2(1.7)	0(0.0)	2(1.8)	4
Total	115(100.0)	113(100.0)	109(100.0)	337
	X^2=23.4, *df*=8, **P<0.01			

Note: *N*=Number of respondents

magazines as a major source; on the other hand, the science museum was a less important source of dinosaur-related information for them (X^2=23.4, *df*=8, p<0.01) (Table 10).

Some children noted that they began to learn about dinosaurs during an early stage of their elementary school years when they were attracted by these interesting animals. Moreover, parents usually played the role facilitators when their children were learning about dinosaurs. A 6th grader recalled the ways her parents helped her acquire information about dinosaurs when she was a lower grader:

> After my parents discovered my interest in dinosaurs, they encouraged me by bringing me to the dinosaur gallery in the science museum, selecting and purchasing dinosaur-related reading materials such as books, and using magazines or films to introduce me to the dinosaurs.

The probable reason parents assisted their children so actively is that they thought of dinosaurs as part of scientific knowledge; they felt their children could nurture a good basis and positive attitude towards science learning by learning about dinosaurs. However, according to the findings of this study, children's interest in studying dinosaurs declined after entering higher grades. One of the major reasons is that older elementary students have become more interested in other novel things. A male elementary school science teacher who helped interview the students tried to explain such changes based on his observations and his experience with children:

> Their work load also influenced children's willingness to keep their focus on dinosaurs. Their teachers and parents begin paying more attention to the students' academic achievements. Therefore they no longer have time to study subjects, such as dinosaurs, that are unrelated to their classes. ...Moreover, parents usually arrange lots of learning activities such as Chinese composition, English conversation, and music lessons etc. after class for their kids. The fact that many skills must be learned directs students' attentions to a relatively broader field.

In this case, parents are no longer facilitators for their children to learn about dinosaurs. On the contrary, their role becomes that of an "inhibitor" as their children grow up.

7. Perceptions of Elementary Students Towards the Existence of Dinosaurs

Most of the children believed that dinosaurs do not exist it the present world: All kinds of dinosaurs are extinct (Table 11). However, 7.5% of respondents thought that dinosaurs are still alive on earth. About 13.5% of students possess other naive perceptions about the existence of the dinosaurs. Such perceptions include: (1) Dinosaurs are mythical animals, (2) dinosaurs are man-made creatures in from films, and (3) dinosaurs are artificial models or toys for enjoyment. Among these ideas, the dinosaurs as models or toys was chosen by the fewest students.

Students at different grade levels also had significantly different perceptions about these propositions (X^2=50.9, *df*=10, p<0.001). The fact that dinosaurs are extinct was recognized by 83.8% of the 4th graders. In comparison, about 70% of the 2nd and 6th graders hold such a belief. Moreover, more 6th graders

Table 11. Elementary Students' Perceptions about the Current Existence of Dinosaurs

Variables	1 *N* (%)	2	3	4	5	0
Grade						
2	161(72.9)	7(3.2)	12(5.4)	28(12.7)	7(3.2)	6(2.6)
4	181(83.8)	12(5.6)	10(4.6)	9(4.2)	2(0.9)	2(0.9)
6	158(73.8)	30(14.0)	10(4.7)	8(3.7)	2(0.9)	6(2.9)
	X^2=50.9, *df*=10, ***P<0.001					
Gender						
Male	254(75.4)	36(10.7)	14(4.2)	16(4.7)	7(2.0)	10(3.0)
Female	245(78.3)	13(4.2)	18(5.8)	29(9.3)	4(1.2)	4(1.2)
	X^2=19.1, *df*=5, **P<0.01					
Total	500(76.8)	49(7.5)	32(4.9)	45(6.9)	11(1.7)	14(2.1)

Notes: 1=Extinct animals, 2=Still alive on earth, 3=Mythical animals, 4=Fabulous animals in films, 5=Artificial models or toys, 0=No response; *N*=Number of respondents

Table 12. Perceptions of Elementary Students about the Current Existence of Dinosaurs

Variables	1 *N* (%)	2	3	4	5	0
Male Grade						
2	88(76.5)	5(4.3)	5(4.3)	12(10.4)	3(2.6)	2(1.7)
4	93(82.3)	9(8.0)	5(4.4)	2(1.8)	2(1.8)	2(1.8)
6	73(67.8)	22(20.2)	4(3.7)	2(1.8)	2(1.8)	6(5.5)
	X^2=40.2, *df*=10, ****P*<0.001					
Female Grade						
2	73(68.9)	2(1.9)	7(6.6)	16(15.1)	4(3.8)	4(3.8)
4	87(85.3)	3(2.9)	5(4.9)	7(6.9)	0(0.0)	0(0.0)
6	85(81.0)	8(7.6)	6(5.7)	6(5.7)	0(0.0)	0(0.0)
	X^2=29.7, *df*=10, ***P*<0.01					

Notes: 1=Extinct animals, 2=Still alive on earth, 3=Mythical animals, 4=Fabulous animals in films, 5=Artificial models or toys, 0=No Response; *N*=Number of respondents

(14%) considered dinosaurs to be living animals than students in the other two sampled grades. Over 12% of the 2nd graders held naive ideas such as dinosaurs being merely creatures existing in films. If the three kinds of naive ideas are combined, they are held by a relatively higher proportion of 2nd graders (21.3%) than 4th (9.7%) and 6th (8.3%) graders.

If the two genders are considered separately through the three age groups, significant differences exist not only in the male (X^2=40.2, *df*=10, *p*<0.001) but also the female group (X^2=29.7, *df*=10, *p*<0.01) (Table 12). In both male and female groups, more 4th grade students regarded the dinosaurs as extinct creatures than those in the other two grades. In addition, more 6th graders think dinosaurs are still alive on earth for both girls and boys. The proportion of male 6th graders with such a belief exceeds 20%. Compared with the other two grades, there are more male and female 2nd graders with the belief that dinosaurs are fictitious animals existing only in films. For the 2nd graders, the proportion of girls with naive ideas was 25%, but that of the male group was only 17%.

Table 13. The Perceptions of 6th-Grade Students about the Current Existence of Dinosaurs

Items	Male *N* (%)	Female *N* (%)
Extinct animals	73(67.0)	85(81.0)
Still alive on earth	22(20.2)	8(7.6)
Mythical animals	4(3.7)	6(5.7)
Fabulous animals in films	2(1.8)	6(5.7)
Artificial models or toys	2(1.8)	0(0.0)
No Response	6(5.5)	0(0.0)
	X^2=21.2, *df*=5, ****P*<0.001	

Note: *N*=Number of respondents

If we consider the effect of gender for each sampled grade, a significant difference exists only in the 6th grade for belief in the survival of dinosaurs (X^2=21.2, *df*=5, *p*<0.001) (Table 13). Over 80% of female 6th-grade students believe that dinosaurs are extinct. Only 67% of the boys in the same grade hold such a belief. But for another item, relatively more boys in the 6th grade believe dinosaurs are still alive on earth. There is a 12.6% discrepancy between the two sexes for this question.

According to the interviews, some students in the lower grades regarded some existing reptiles such as crocodiles, turtles, etc. as the descendants of the ancient dinosaurs. Based on biologists' research, this is a misconception about the classification of reptiles. However, those 6th graders who indicated dinosaurs were still alive on earth held relatively more thoughtful arguments. Some of them stated that dinosaurs are not extinct because they evolved into the birds. Others mentioned that certain monsters reported in the mass media might be the descendents of the dinosaurs. A male 6th grader's explanation represents the first position:

> I think dinosaurs theoretically still exist on earth. From science books, I learned birds evolved from dinosaurs. Based on such evidence, dinosaurs exist on earth in the other forms.

Another view held by children about the existence of the dinosaurs is that they believe some reported monsters might be the living dinosaurs. A child told the interviewer:

> The monster described by the visitors and residents near Loch Ness is one kind of dinosaur. A few people said they have seen it. Its picture was taken, too. From the picture, it has a long neck; however, the large portion of its body is in the water. Judging from the scale, I estimate it is very large.

Another student said:

> I believe there are dinosaurs still alive. Although no direct evidence has been provided, a lot of reports tell

> us about the existence of the dinosaurs. Since human being cannot explore every corner of the earth, we cannot to be sure obscure creatures are not dinosaurs.

Both students are 6th graders. The possession of more information related to but not confined to the subject of dinosaurs apparently led them to construct their own logical explanations about the existence of dinosaurs. Such an effect existed especially for students in the higher grades. Their knowledge about fabulous monsters or obscure creatures makes them think some dinosaurs still exist on Earth.

8. Most of Reasons for the Extinction of the Dinosaurs Given by Elementary Students Were Connected with Environmental Changes

Reasons for the extinction of the dinosaurs given by elementary students include:

(1) a hit on Earth by a meteorite,
(2) the eruption of volcanoes,
(3) earthquakes,
(4) lack of food,
(5) environmental changes: cold weather, ...
(6) poisoning from eating harmful plants,
(7) failure to compete with the mammals,
(8) continental drift,
(9) emigration to other planets.

Children usually gave more than one reason to explain why the dinosaurs were extinct. Students in the higher grades or who possessed more information about dinosaurs were more able to explain the reasons for the extinction of the dinosaurs by organizing some of the above factors in a more logical way. On the other hand, younger students revealed their relatively naive ideas when they explained why the dinosaurs did not survive on earth. The logical connections between the factors mentioned in their explanations were less well-developed. For instance, when asked why there were no dinosaurs in the current age, a first-grade student who had visited the dinosaur gallery of the science museum accompanied with his parents explained:

> All of the dinosaurs were dead so there are no dinosaurs left on earth. At first volcanoes erupted. A lot of hot rocks were spilled. After the eruptions, it began to snow. The dinosaurs could not touch the snow because it was extremely cold. Lots of dinosaurs were frozen to death. Only if a typhoon came, the snow would be blown far away from the area. Therefore, snow would not cause the extinction of the dinosaurs. Besides, the heat from the eruption of the volcanoes also made the snow melt. Thus, there was no disaster for the dinosaurs.

The fact that this student connected the eruption of volcanoes with snowing is no consistent with the cause-effect relationship. In his point of view, weather change induced a difficult environment for the dinosaurs. However, the cause of cold weather was quite irrelevant to the real phenomena. This student used snow caused by the volcanic eruption to explain why the cold weather occured. The various kinds of naive explanations were more easily discovered in the interviews. For instance, a second-grade student indicated that the dinosaurs became extinct because they directly touched hot materials that had erupted from the volcanoes. Although both students mentioned volcanoes, one thought cold and another thought hot was the immediate factor that killed the dinosaurs.

Compared with the younger students, the explanations provided by higher graders were more science-based and conformed better with logical relationships. For example, a fifth-grade student interviewed in the dinosaur gallery also mentioned volcanic eruptions as the major reason, but his reasoning was more logical:

> The dust from the eruption of the volcano covered the atmosphere. The clouds were so thick that sunlight was not able to penetrate. Consequently, the plants growing on the surface of the planet could not absorb enough light energy to produce nutrition. Therefore these plants failed to survive. The herbivous dinosaurs were affected and died first. Other dinosaurs with meat-eating habits died because there were no living animals as food. All of the dinosaurs died in the long run.

This student adopted the concept of the food chain as the basis for his explanation. Although also mentioning clouds in the atmosphere, another student indicated a different source–the impact on the earth by a meteorite from outer space. But he shortened the time period needed for the extinction to occur. He said:

> The earth was suddenly hit by a comet. And then the dust rose from the surface of the earth. The planet was shaded by the thick cloud layer formed from the dust. Such a cloud layer lasted for several months. All of the dinosaurs finally became extinct because they could not endure the consequent humid and dark weather.

The following responses can be also provided to help us understand children's tendency to simplify both the elements and the time scales of the story:

(1) The dinosaurs were killed by falling meteorites.

(2) The dinosaurs were killed by falling materials caused by earthquakes.

(3) The dinosaurs were scorched to death by boiling substances from volcanoes.

(4) The dinosaurs could only survive in warm areas. If they moved to the south pole, they would die. Actually the dinosaurs were carried to the arctic zone in the ice age because of continental drift. Finally, all of the dinosaurs were frozen to death.

Judging from the reasons provided by students, it is the life history of the individual, not the whole population, that serves as the basic knowledge for their explanation of the extinction of the dinosaurs. Examining the way they answered this unsolved scientific problem, we may conclude that most elementary students do not have explicit prior knowledge about the difference between the life history of individual organisms and of a whole population of a species. The students are inclined to shorten the time needed for the whole event, simplify or delete some of the steps, and/or connect the possible reasons in an illogical way. Besides their level of mental development, the limited information possessed by the kids is also believed to play role in this.

VI. Discussion and Recommendations

The task of studying children's perceptions and/or misconceptions about a specific scientific concept involves two perspectives. First, in a relatively short-term perspective, the findings could be regarded as a body of descriptive findings elicited and categorized by science educators. Such findings provide information about children's understandings of scientific concepts. In the second perspective, the findings may serve as a foundation for further prescriptions. For classroom teachers, the development and adoption of appropriate teaching strategies should be based on what is known about the students. However, as educators in the science museum, the possession of knowledge about the students' responses toward certain topics would allow the curators to consider what role they may play in the collaborative relationship with the school system. But if the scientific concepts studied are directly based on the exhibits themselves, the results could serve as a basis for the work of designers and educators in the museum. Therefore, not only is an evaluation indispensible to the process of developing exhibits–the so-called formative evaluation–but a summative evaluation conducted by the curators is required for refining permanent exhibits. For science educators in the broad sense, the results of the evaluation provide knowledge to help understand students' science learning. However, on the other hand, if the data is analyzed from the standpoint of the museum educators, the prescriptive function for the educational function of the museum may be emphasized.

The dinosaur gallery is one of the most focal points for children visiting NMNS. Most of the students participating in the study indicated that the dinosaur gallery in NMNS was their main source of information concerning dinosaurs. However, unlike other countries, no dinosaur fossils have been found in Taiwan. Therefore, the permanent exhibits in the dinosaur gallery are not real fossils. But when we examined the level of the students' interest in dinosaurs, the response of youngsters in Taiwan was found to be at quite a high level, even if dinosaurs are not introduced well in their elementary school textbooks. It seems that the lack of direct experience of real fossils is somehow replaced by other experiences such as exhibits in the form of miniatures, models, films, simulation games, and demonstration boards and also information provided by the mass media and personal contact. The results of this study have supported Solomon's arguments (Solomon, 1987) concerning social influences on children's science learning.

Based on the results of this study, the following recommendations may help both school and museum educators consider ways for applying the topic of dinosaurs to science teaching in the school classroom and museum exhibit halls.

(1) Due to the interest expressed by the majority of elementary students, the topic of dinosaurs could be used as a vehicle and motivational device for children to understand the biological diversity of the Earth, the impact of the environment on living organisms, the reasons for extinction and the mechanism of competition. If approached correctly, the study of dinosaurs could become one of the best topics for introducing children to the fascinating world of nature.

(2) Children acquired their knowledge of dinosaurs through a variety of the channels outside the classroom. Most of them, constructed knowledge of dinosaurs that is incompatible with what scientists have reported. It is suggested that teachers mention this topic while teaching related topics in the classroom and introduce it in a systematic way to help students correct their own concepts.

(3) Children's perceptions about dinosaurs come

from several channels. Certain channels primarily serve entertainment purposes rather than achieving educational goals. Moreover, some published books introducing dinosaurs are found to contain mistakes. In this situation, the images of dinosaurs formed by children are more or less divergent from the scientific view. For instance, *Plesiosaurus*, which is not dinosaur, is found include as one of the typical examples dinosaurs in some publications for children. There is no doubt children will gain incorrect information if they read such books. Because the editors of children's books don't necessarily have a science background, it is suggested that books being published should be examined by experts on dinosaurs.

(4) More students in the lower grades mentioned the science museum was their main source for obtaining information about dinosaurs. Compared with younger students, more older students learned about dinosaurs by reading materials such as books and magazines, etc. It is suggested that awareness and interest should be increased in appropriate ways for younger students. In contrast, the provision of more information about dinosaurs should be emphasized in the higher grades.

(5) The content of exhibit labels in the dinosaur gallery is one of the sources of information about dinosaurs for elementary students. However, some Chinese terms translated from the scientific names are likely to mislead students' understanding of the dinosaurs. Based on such a finding, we suggest that the Chinese names of some dinosaurs need to be re-considered to avoid causing misunderstandings.

(6) In order to help students construct knowledge of dinosaurs based on scientific findings, both teachers and parents should be encouraged to visit the dinosaur gallery of the science museum together with their children. It is also suggested that exhibits, models, simulation games, films, multimedia, and the services of interpreters should be utilized in a systematic way.

According to Lucas (1983), most of people learn outside the school system most of their lives. Along with the concept of life-long learning, informal educational resources will play a more important role in learning in the future. Especially for schoolchildren, the opportunity to explore the science museum will help them to nurture interest in and motivation for learning and utilizing social educational resources from an early stage of life. Tamir's study (Tamir, 1990) also indicated that field trips to informal institutions such as museums, zoos, and outdoor areas have a positive effect on students' learning. As a focal point for visits, the dinosaur gallery could be used to reinforce children's recognition of certain biological concepts, and also provide informal educational resources for long-term utilization over a lifetime. Since dinosaur concepts are not introduced well in textbooks, children's perceptions of dinosaurs are not narrowed by the scope of formal education. Understanding of the freedom of children' thoughts on this topic may give us an opportunity to re-consider the goals of science teaching and the ways we achieve them.

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國小學童對恐龍相關概念認知之研究

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摘　　要

恐龍在兒童心目中有著難以解釋的魅力；在世界各大自然史博物館中，與恐龍有關的收藏與展示經常是最吸引觀眾目光的焦點。尤以與恐龍有關之概念在我國現行之中、小學教材中十分有限，相較於坊間傳播媒體以及非制式教育管道所扮演角色的豐富而多樣，有關國小學生對恐龍的認知及態度研究在探討社會互動因子對學生學習的影響，自有其特殊之價值。

本研究旨在探究國小學生對恐龍之相關認知。研究中除採用自行發展之問卷對二、四、六年級學生進行紙筆測驗外，並藉深入訪談蒐集質性資料。研究發現國小男、女生間對恐龍的喜好程度存在有顯著的差異；表達喜歡恐龍的男生遠多於女生。在本研究中亦由學生列舉了喜歡恐龍的原因，以及最受喜歡的恐龍種類。其他諸如有關造成學生對恐龍相關迷思概念的來源，獲得恐龍相關知識來源的變化，對恐龍存在的看法，以及其滅絕的原因等項目，在本研究中亦一併討論。

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The Relationship between Biology Cognitive Preferences and Science Process Skills

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ABSTRACT

This study employed the Test of Biology Cognitive Preference (TBCP) to determine the biology cognitive preference styles of 1,339 seventh grade students in the Taipei area of Taiwan. The relationship between biology cognitive preferences and achievement in science process skills was then explored.

The results showed that the subjects exhibited a cognitive preference style of Questioning (*Q*) > Principles (*P*), Applications (*A*) > Recall (*R*). This indicated that the subjects displayed the highest preference for questioning and the lowest preference for memorizing biological information presented to them.

Performance in science process skills was measured by the Test of Science Process Skills (TSPS). Results from TBCP and TSPS were analyzed using a correlation technique. TSPS scores correlated positively with *Q* preference scores, but negatively with *R* preference scores in biology ($p<0.01$). However, no significant correlations were found between performance in science process skills and scores for the *P* and *A* preference modes.

When the subjects were categorized into three different achievement levels, according to the TSPS scores, namely as high (*H*), medium (*M*), and low (*L*) achievers, oneway ANOVA revealed significant main effects for biology cognitive preferences across the three groups of subjects.

A strong preference for questioning and a weak preference for recall of biological information were associated with high achievement in science process skills. On the other hand, strong preferences for application and principles and weak preferences for recall and questioning were associated with low achievement in science process skills. Generally, it was evident that the biology cognitive preference styles exhibited by high achievers were significantly different from those exhibited by low achievers.

Key Words: biology cognitive preference, science process skills

I. Introduction

The construct of cognitive preferences was first introduced by Heath (1964) as an alternative way to evaluate the effectiveness of science curriculum. The idea was based upon the hypothesis that, when learning science, students not only acquire scientific knowledge, but also develop particular modes of preference in dealing with scientific information. Consequently, the science cognitive preferences exhibited by students in inquiry-oriented and conventional science curricula are expected to be different. Students using a more inquiry-oriented science curriculum should exhibit a higher preference for principles and questioning compared to those who use a more traditional science curriculum (Heath, 1964; Tamir, 1977).

Heath (1964) proposed four different modes of cognitive preference in science, namely, Recall (*R*), Principles (*P*), Questioning (*Q*), and Application (*A*). Based upon Heath's definitions, van den Berg (1978) described the four cognitive preference modes as follows:

(1) Factual Information or Recall (*R*)

A person responding in this mode likes to store or memorize scientific information in the same form it is presented. The "storing" is without any processing such as trying to relate information to other information, or abstracting a general rule or principle from specific data, or questioning the validity of the information. A preference for recall indicates interest in learning terms, definitions, facts, observations, or concepts.

(2) Principles (*P*)

A person responding in this mode likes to extract general principles or rules from the information presented, or looks for interrelationships between scientific information. A preference for principles indicates interest in identifying relationships between variables, in learning rules that can be applied to a class of objects, organisms, phenomena or variables, or in explaining phenomena in terms of general principles or theories.

(3) Questioning (*Q*)

A person responding in this mode likes to evaluate scientific information critically, looking for overgeneralizations and limitations. A preference for questioning indicates interest in critically analyzing and commenting on the validity of scientific information, and/or in generating suggestions and hypotheses for further research.

(4) Applications (*A*)

A person responding in this mode tends to evaluate scientific information in terms of its applicability. A preference for applications indicates interest in using scientific information to solve problems in commerce, industry, farming, daily life, or science.

Cognitive preference tests based upon Heath's notion typically consist of items including an introductory statement followed by four alternative extended statements, one for each of the four preference modes. The examinees are told that all the four alternatives are correct and are asked to rank or rate the four alternatives according to their degree of preference. Since Heath proposed his idea of cognitive preferences, quite a few instruments purported to measure science cognitive preferences have been developed. It was evident that cognitive preferences in science could provide useful information about students' thinking that might better inform biology teachers' planning and teaching.

The importance of cognitive preference assessment lies, as suggested by Heath (1964), not in whether the student can identify correct information, but rather in what (s)he is likely to do with information intellectually. Therefore, a cognitive preference test does not attempt to measure students' achievements, but rather attempts to adequately reveal students' particular modes of thinking or preferences in dealing with scientific information presented to them. Such epistemic information can be useful in structuring learning experiences and addressing specific abstract or practical topics.

1. Importance of the Study

Since the 1970s, major science education reforms in Taiwan have transformed science learning from merely memorizing scientific facts and concepts to fostering understanding of fundamental principles and developing intellectual skills related to the acquisition and evaluation of scientific knowledge. Hence, the biology curriculum currently implemented in junior high schools places more emphasis on the learning of scientific principles and developing inquiry skills than did the former biology curriculum. When this curriculum attains its intended goals, then the students will have developed basic science process skills in addition to the learning of biological concepts, and exhibit a preference for analyzing scientific information critically rather than merely memorizing scientific knowledge. Unfortunately this assumption has not been formally tested. Exploration of the modes of preference in cognition that the students exhibit in processing scientific information and of the relationships between students' science cognitive preferences and achievements in science are reasonable first steps in testing the assumption.

Within the last two decades, research has indicated that students' cognitive preferences may vary from subject to subject, and even from topic to topic within a subject (Cheng, Huang, Tsai, & Liaw, 1993a; Rost, 1983; Tamir, 1975; Tamir & Jungwirth, 1984; Tamir & Lunetta, 1978). A recent study done in Taiwan (Cheng, Huang, Tsai, & Liaw, 1993b) has shown that seventh grade students, after studying the "new" biology curriculum, exhibited a strong preference for the P mode and a weak preference for the R mode. The study also indicated that there were significant differences in cognitive preferences between males and females, and among students in different types of schools. Some results of the study were different from what has been found in studies done in other countries (Tamir, 1985). What this means and how cultural and educational backgrounds contribute to the development of cognitive preferences in students are questions that need to be explored further.

The relationship between cognitive preferences and achievement in science has also been a major focus of investigation in previous researches. Although many studies have shown that there was a close relationship between cognitive preferences and achievement in science (Tamir, 1976, 1977, 1988; Tamir & Kempa, 1978), their results were relatively diverse. Several studies found that science achievement correlated positively with the Q mode, and negatively with the R mode (Cheng & Yang, 1995; Kempa & Dube, 1973; Tamir, 1988; Tamir & Yamamoto, 1977). Others showed that while biology achievement correlated positively with the A mode, no significant correlation was found between biology achievement and the Q mode (Barnett, 1974).

Although studies have attempted to investigate the relationship between cognitive preferences and several aspects of achievements in science, very few have focused on science process skills achievement. In a study utilizing ninth grade students as subjects, Atwood & Stevens (1978) found that students with a strong preference for the A mode showed greater achievement gains in science process skills than students with a weak preference for the A mode. However, the conclusions of their study were neither comprehensive nor definitive. Since science process skills, such as interpreting data and formulating hypotheses, constitute an essential part of inquiry-based logical thinking and reasoning, it is anticipated that students should develop these skills in their learning of science. Hence, whether or not substantial associations exist between students' cognitive preferences and the learning of science process skills is an issue that needs to be further investigated.

2. Purpose of Study

The purpose of this study was to determine the biology cognitive preference styles of seventh-grade students in the Taipei area of Taiwan, and to explore how the students' cognitive preferences related to their learning of science process skills.

II. Methods

1. The Subjects

The subjects consisted of 1,339 seventh-grade students selected from the Taipei area (Taipei City and Taipei County) employing stratified random sampling and cluster sampling methods. Firstly, the junior high schools in Taipei City and Taipei County were divided into three types according to their size, i.e., total number of classes. The three types of schools were termed large (above 76 classes), medium (31-75 classes), and small (below 30 classes) schools. Then, an adequate number of schools and classes were drawn from the three types of schools based on the ratio of the total number of classes in each type of school. All of the students in the classes selected were the subjects of this study. A total of 1,339 students were selected from three large, two medium and two small schools.

2. Assessment of Biology Cognitive Preference

The Test of Biology Cognitive Preference (TBCP), developed by Cheng *et al.* (1993b), was employed to assess the biology cognitive preference styles of the subjects. The TBCP consisted of 32 items. Each item was composed of a statement and four optional extended responses, each of which represented one of the four cognitive preference modes. In order to ensure that the subjects were familiar with the information contained in the TBCP, the construction of the items was based exclusively upon the current junior-high biology textbook.

The reliabilities of the TBCP, as reported in the validation study, were satisfactory for the purpose of this study. The internal-consistency reliability coefficients were 0.86, 0.79, 0.90, and 0.67 for the *R* (Recall), *P* (Principles), *Q* (Questioning), and *A* (Application) modes, respectively. It was also evident that the TBCP possessed fairly satisfactory content and construct validity (Cheng *et al.*, 1993b).

The TBCP was administered to the subjects ipsatively at the end of the second semester. The subjects were informed that all of the four options were correct and were asked to rank the four options according to their relative preference. The answer sheets were scored using a data transformation program which allotted "4" to the most preferred response, "3" and "2" to the next preferred, respectively, and "1" to the least preferred response.

3. Assessment of Science Process Skills

The science process skills of the subjects were measured by the Test of Science Process Skills (TSPS). The TSPS consists of two types of items: 17 multiple-choice items and 13 short constructed-response items. Among them, 4 items were developed by the author, and 26 items were selected, adapted and intensively modified from constructed-response type items originally developed by Mao (1988, 1989) for measuring inference, prediction, and data interpretation skills.

Since the TSPS was recomposed from parts of tests developed previously, it was imperative for this study to examine the reliability of the test. In this study, the internal-consistency reliability (Cronbach alpha) was 0.80 and the test-retest reliability was 0.84 (Table 1). This reliability was considered satisfactory for the purposes of this study. The content validity of the TSPS, which was established by an expert panel, was satisfactory.

III. Results and Discussion

1. Reliability and Interrelationship among Cognitive Modes

There are two different ways reported in the literature for a person to respond to a science cognitive preference test. They are ipsative and normative methods (Tamir & Lunetta, 1977). Although the ipsative method has been questioned regarding the validity of the data obtained, Tamir & Lunetta (1977) provided strong support for the use of the ipsative method in science cognitive preference research. They further indicated that the ipsative method discriminated more clearly between different cognitive patterns are that the danger of distorted relationships is not as severe as might be expected.

In the present study, the TBCP was administered to the subjects ipsatively (ranking). Data analysis indicated that the Cronbach alpha reliability coefficients of the four preference modes were satisfactory (Table 2), and were consistent with what has been found in previous studies of 7th graders (Cheng *et al.*, 1993b; Cheng & Yang, 1995).

The intercorrelations of scores of the four cognitive preference modes are also presented in Table 2. Since the data were ipsative in nature, an individual's scores on the four preference modes were interdependent. Students who displayed a high preference for a particular preference mode would naturally display a low preference for other preference modes and vice versa. It was thus anticipated that some of the correlation coefficients among the four cognitive preference scores would be negative. This interdependency should be taken into account when interpretations of the correlation coefficients are made.

Table 1. Mean, Standard Deviation (*SD*), and Reliability Coefficients of the TSPS Scores

Mean	*SD*	Coefficient Alpha	Test-Retest Correlation
19.07	5.04	0.80 (*N*=1339)	0.84 (*N*=91)

An examination of the intercorrelations among scores of the four cognitive preference modes shown in Table 2 indicates that a positive but somewhat low correlation exists between scores of R and P preference modes. However, strong negative correlations are found between scores of R and P modes and those of Q and A preference modes. In all respects, the results shown in Table 2, except the correlation between the Q and A modes, are quite similar to those predicted by the cognitive preferences model (Heath, 1964) and to those reported in previous studies in which students of the same grade level were investigated (Cheng *et al.*, 1993b; Cheng & Yang, 1995). However, no statistically significant positive correlation was found between scores of Q and A preference modes. This phenomenon was somewhat different from theoretical expectations and the findings of the two studies mentioned above. A recent meta-analytic study of cognitive preferences showed that the mean correlation between Q and A modes was -0.15 with a standard deviation of 0.29 (Tamir, 1985). This implies that relatively weak, moderately fluctuating correlations between scores of Q and A preference modes might be anticipated.

The pattern of intercorrelations shown in Table 2 confirmed the existence of two opposite scales, the *Q-R* and *A-P* scales, within the four biology cognitive preference modes. They were referred to as "scientific curiosity" and "scientific utility" scales, respectively, in previous studies (Kempa & Dube, 1973; Tamir, 1975).

2. Biology Cognitive Preferences and Science Process Skills

The mean and standard deviations of scores obtained for the four preference modes are shown in

Table 2. Coefficient Alpha and Intercorrelations of Scores of the Four Cognitive Preference Modes (*N*=1339)

Preference Mode	R	P	Q	A
Coefficient Alpha	0.84	0.75	0.88	0.67
R (Recall)	1.00			
P (Principles)	0.25*	1.00		
Q (Questioning)	-0.81*	-0.52*	1.00	
A (Application)	-0.35*	-0.58*	0.07	1.00

* Significant at the 0.01 level.

Table 3. The ranking order of the mean scores for the four cognitive preference modes from the highest preference to the lowest preference was *Q>P,A>R*. The ranking order of the P, Q and A preference modes was different from what had been found in a previous study (Cheng & Yang, 1995) in which the ranking order of mean scores from highest preference to lowest preference was *P>A>Q>R*. Oneway ANOVA and subsequent multiple range tests showed that scores for the Q, P, and A modes were significantly higher than those of the R mode. However, no significant differences were found among scores of Q, P, and A modes. This suggested that the differences between the findings of the two studies were not drastic. The results indicated that the subjects of the present study prefer to question biology information presented to them more than to just memorize it. They also indicated that the current junior high biology curriculum has largely attained its intended goals.

The mean value of *Q-R* (*Q* minus *R*) as shown in Table 3 was 0.25, a value higher than that obtained previously (Cheng & Yang, 1995). The high and positive *Q-R* value (representing the scientific curiosity scale) may be, as stated by Kempa & Dube (1973), "an indication of students' willingness and desire to acquire scientific knowledge beyond that already possessed" (p. 287). But Jungwirth (1980) gave an alternative interpretation for this bipolar *Q-R* phenomenon by contending that "high *Q* scores indicate willingness to go beyond the familiar, low *R* scores indicate a distaste for the already familiar-an intrinsic dissatisfaction with knowledge already gained and hence memorized" (p. 92). Since biology achievement was correlated positively with *Q* scores and negatively with *R* scores, it seems that Jungwirth's statement is more appropriate for interpreting the data obtained in this study. The mean value of *P-A* (*P* minus *A*) was around 0. This indicated that the "scientific utility scale" was not as distinct as "scientific curiosity scale". This phenomenon might also indicate that, in general, the subjects as a whole did not express a preference for conceptual knowledge or application of knowledge. However, a standard deviation of 0.61 (Table 3) showed that the preferences for conceptual knowledge (R) and for application of knowledge (A) as exhibited by individual students were somewhat different.

Since the biology curriculum received by the subjects was inquiry-oriented, and one of the goals of the curriculum is to foster inquiry skills relating to the processes of science, the biology cognitive preferences of students taking this curriculum should reflect this trend. Therefore, it is important for this study to examine the relationships between students' biology cognitive preferences and achievement in science process skills. Data presented in Table 4 shows that achievement in science process skills as measured by the TSPS correlated positively with scores for the Q preference mode and *Q-R* scale, and negatively with scores for the R preference mode ($p<0.01$). No significant correlations were found between achievement in science process skills and scores for the P and A preference modes together with the *P-A* scale. However, a low but significant correlation was found between scores on the multiple-choice subtest of the TSPS and scores for the P preference mode.

Since the effects of the "new" biology curriculum will likely be different for more successful students and less successful students, the sample was categorized by TSPS achievement. If the subjects were purposefully categorized into high (*H*, above +0.5 *SD*), medium (*M*, between +0.5 *SD* and −0.5 *SD*), and low (*L*, below −0.5 *SD*) performance groups according to TSPS scores, comparisons of biology cognitive preferences among the three groups of subjects could thus be made. Oneway ANOVA revealed that significant differences in scores for R and Q preference modes and the *Q-R* scale were found across the three groups of subjects. No significant differences in scores for P and A preference modes and the *P-A* scale were found across the three groups of subjects (Table 5). A subsequent multiple range test revealed that the high group exhibited the strongest preference for the Q

Table 3. Means and Standard Deviations (*SD*) of Scores of the Four Cognitive Preference Modes (*N*=1339)

Preference Mode	R	P	Q	A	Q-R	P-A	MRT Among Four Modes*
Mean	2.32	2.55	2.58	2.55	0.25	0.00	R:P, R:Q,
SD	0.46	0.36	0.54	0.33	0.94	0.61	R:A

* In the Multiple Range Test, only pairs of comparisons significantly different at the 0.05 level are reported.

Table 4. Correlations between Scores of TBCP and TSPS (*N*=1339)

Preference Mode	R	P	Q	A	Q-A	P-A
TSPS#	-0.30*	0.05	0.25*	-0.03	0.29*	0.05
TSPSCR#	-0.24*	0.01	0.21*	-0.02	0.24*	0.02
TSPSMC#	-0.29*	0.07*	0.22*	-0.04	0.26*	0.06

* Significant at the 0.01 level.

TSPS : Test of Science Process Skills

TSPSCR : TSPS --- Constructed Response Subtest

TSPSMC : TSPS --- Multiple-Choice Subtest mode and weakest preference for the R mode. Conversely, the low group exhibited the strongest preference for the R mode and the weakest preference for the Q mode.

Data presented in Table 5 also showed that the biology cognitive preference orientation of the subjects, which was represented by the rank order of the four preference modes from highest to lowest, was *Q>P,A>R*, *P,Q,A>R*, and *A,P>R,Q*, for the high (*H*), medium (*M*), and low (*L*) groups, respectively. These results seemed to show that, for 7th grade students, a strongest preference for critical questioning (Q mode) and a weakest preference for recall (R mode) of biological information were associated with superior performance in science process skills. Strong preferences for principles (P mode), questioning and application (A mode), and a weakest preference for recall of biological information were associated with medium performance in science process skills. On the other hand, strong preferences for application and principles, and weak preferences for recall and questioning of biological information were associated with inferior performance in science process skills.

These findings were different from, if not contradictory to, those reported by Atwood & Stevens (1978). In a study with 9th-grade students as subjects, they reported that a strong preference for the application of information (A mode) indicated science process skill achievement, and that a preference for recall or questioning scientific information was neither an advantage nor a disadvantage to achievement in science process skills.

Science process skills are essentially intellectual skills which students use to process scientific information. Science cognitive preferences represent particular preference modes students display intellectually in dealing with scientific information presented to them. Therefore, to know, in essence, what relationship exists between these two cognitive processes should be an indication of students' willingness to use science processes to interpret information. This should also be of great interest to science educators. Since very little study has been done in this area so far, obviously, more studies need to be done before we can draw any conclusions concerning how science cognitive preference styles are related to the learning of science process skills, and what a science teacher can do to promote superior performance in science process skills.

IV. Conclusions

From the above findings, it was concluded that 7th grade students in Taiwan exhibited a strong preference for questioning (Q mode) and a weak preference for memorizing (R mode) biological information

Table 5. Differences in Biology Cognitive Preferences among Three Groups of Subjects Categorized by TSPS Scores

Preference Mode		TSPS Scores Category#			F Prob. (2,1338)	Multiple Range Test*
		H (*N*=446)	*M* (*N*=513)	*L* (*N*=380)		
R	Mean	2.16	2.35	2.48	0.000	H : M; H : L
	SD	0.48	0.44	0.38		M : L
P	Mean	2.56	2.56	2.53	0.320	
	SD	0.38	0.35	0.33		
Q	Mean	2.76	2.55	2.43	0.000	H : M; H : L
	SD	0.57	0.52	0.44		M : L
A	Mean	2.53	2.55	2.56	0.328	
	SD	0.36	0.34	0.27		
Q-R	Mean	0.60	0.20	-0.05	0.000	H : M; H: L
	SD	1.00	0.90	0.77		M : L
P-A	Mean	0.03	0.02	-0.04	0.269	
	SD	0.67	0.61	0.53		
MRT Among Four Modes*		R : P, R : Q R : A, P : Q Q : A	R : P, R : Q R : A	R : A, P : Q Q : A		
TSPS	Mean	24.40	19.12	12.74		
	SD	1.90	1.43	3.01		

# *H*, *L*, and *M* represent above +0.5 *SD*, below -0.5 *SD*, and in between, respectively.

* In the Multiple Range Test, only pairs of groups significantly different at the 0.05 level are reported.

presented to them. This provided strong support for the claim that the biology curriculum currently used in junior high schools has partially attained its intended goals.

It is evident that, for 7th grade students, achievement in science process skills correlates positively with questioning (Q preference mode), but negatively with recall (R preference mode) of biological information. No statistically significant correlations were found between achievement in science process skills and the P and A preference modes.

A strong preference for critical questioning (Q mode) and a weak preference for memorizing (R mode) biological information were associated with superior achievement in science process skills. However, strong preferences for application (A mode) and principles (P mode) and weak preferences for recall (R mode) and questioning (Q mode) were associated with inferior achievement in science process skills. It is evident that the biology cognitive preferences exhibited by students with high science process skills achievement were significantly different from those of low achievers.

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生物認知偏好與科學過程技能的關係

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摘　要

本研究應用「生物認知偏好測驗(TBCP)」探索台北地區（台北市、縣）總共1339位國中一年級學生的生物認知偏好，並探討生物認知偏好與科學過程技能成就之間的關係。

研究結果顯示全體樣本的生物認知偏好型式，由高至低之順序爲「發問質疑(Q)〉原理原則(P)、應用(A)〉記憶(R)」，顯示台北地區的國中一年級學生於處理其所習得之生物知識時，最喜好批判發問而最不喜好記憶。

樣本之科學過程技能成就（以「科學過程技能測驗(TSPS)」的得分來代表）與Q偏好的分數之間呈顯著正相關，與R偏好分數之間呈顯著負相關($p<0.01$)；而與P和A偏好分數之間則無顯著相關存在。

當將樣本依TSPS的得分畫分爲高(H)、中(M)與低(L)成就三群時，單因子變異數分析(ANOVA)的結果顯示，三群樣本的生物認知偏好型式有顯著差異存在。

表現較高之「發問質疑(Q)」與較低之「記憶(R)」認知偏好的學生，其科學過程技能成就最高；而表現較高之「應用(A)和原理原則(P)」以及較低之「記憶(R)和發問質疑(Q)」偏好的學生，其科學過程成就則最差。一般而言，研究的結果顯示，科學過程技能成就高的學生之生物認知偏好與低成就學生顯著不同。

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Investigation of the Structure and Dimensionality of ILPS Tests Items

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ABSTRACT

Employing statistical methods such as the Quasi-Simplex model, principal component analysis, cluster analysis, and Stout's nonparametric unidimensionality test, we investigated the complexity structure and dimensionality of ILPS test items seeking to measure student performance in six science subject areas.

It was found that the four biology subtests for Grades 6 and 9 (all of which contained items designed to measure the cognitive processes involved in knowledge, understanding, application, and integration) fit the Quasi-Simplex model; however, the observed hierarchical order of complexity for the four Grade 6 subtests differed from the original hypothesis. The results imply: (1) both biology tests are capable of measuring more than simple factual knowledge, and (2) it is more difficult for test writers to create items which accurately measure application and integration abilities than items which measure simple knowledge and understanding.

Use of the single linkage method failed to find consistent patterns of distinct clusters in dendrograms associated with the ten ILPS tests, meaning that items within each ILPS test set maintained a homogenous structure. Results from Stout's procedure revealed that the Grade 9 biology and physics tests failed to support the null hypothesis of essential unidimensionality. The deletion of all items with a first factor loading of less than 0.40 from these two tests resulted in the 10 ILPS tests becoming essentially unidimensional.

Key Words: cluster analysis, dendrogram, indicators of science education, item response theory, nonparametric unidimensional test, principal component analysis, quasi-simplex model

I. Introduction

Under the auspices of the ROC's National Science Council, Shin & Cheng (1994) designed a project to develop pre-college indicators for monitoring and upgrading Taiwan's secondary science education. As suggested by Murnane & Raizen (1988), Smith (1988), Shavelson, McDonnel, Oakes, Carey, & Picus (1987), Shavelson, Carey, & Webb (1990) and Odden (1990), this monitoring system included input, process, and outcome indicators. However, during the project's first phase, Shin and Cheng focused on developing only a single type of outcome indicator: Indicators of Learning Progress in Science Education (ILPS). The completion of five sub-projects resulted in the creation of ILPS test sets for biology, physics, chemistry, earth science, and science process skills (Cheng & Lin, 1994; Fang, 1994; Guo, 1994; Lin, 1995). The stated goals for these ILPS tests are to: (1) evaluate individual science education achievement; (2) compare science education achievement across school districts or geographical regions; and (3) track longitudinal trends locally and nationally over time.

The ILPS test sets were constructed according to two criteria. First, test items must correspond to major curricular objectives – that is, they must allow for the assessment of conceptual knowledge, processing, and higher-order thinking skills in addition to factual knowledge. Second, in order to allow for fair comparisons based on test scores, test item parameters (e.g., difficulty and discrimination) must be invariant to compensate for the effects of those parameters in terms of individual test items. To meet the first requirement, subject-matter experts were asked to construct test items to measure the four cognitive processes of knowledge, understanding, application, and integration for each of the five subprojects. To meet the second requirement, panels of experts intended to use Item Response Theory (IRT) models (Lord, 1980) to calibrate item statistics and assess student performance; the IRT model was chosen because it provides a means of securing item parameters with desired invariance properties.

Assessing items designed to measure cognitive processes involves subjective judgments, and thus requires the use of statistical tools to investigate hierarchical order of learning complexity among items associated with the four cognitive categories. In addition, the legitimacy of using preferred item response models is predicated on an assumption of unidimensionality. This in turn calls for statistical testing for unidimensionality before applying IRT models to calibrate ILPS tests items.

The goal of the present study was to investigate the complexity structure and dimensionality of ILPS test items. It was hoped that the results of such an investigation would: (1) show how quantitative methods can be incorporated to verify the objectivity of a panel study; and (2) provide guidelines for the appropriate use of the IRT model for the calibration of ILPS tests items.

II. Methodology

1. Complexity Structure

Guttman's Simplex Theory (Guttman, 1969) addresses the question of whether or not a set of similar tests form a simple hierarchical order in terms of complexity. This order-factor theory includes two model types: Perfect Simplex and Quasi-Simplex.

Given a set of n tests $t_1, \dots, t_n$ possesses a Perfect Simplex model – that is, the n tests can be arranged in order from least to most complex and correlations between any two tests can be expressed as : $r_{jk}=r_{jg}/r_{kg}$ where $j<k$ in terms of degree of complexity and g is a hypothetical total complexity factor. In addition, the matrix of inter-correlations among the n tests contains the following features: (1) all of the highest correlations are found next to the main diagonal; (2) as correlations move further away from the main diagonal, they decrease to either the left or right; and (3) the highest column or row of sums associated with tests of intermediate complexity are found at or near the middle of the matrix, while the lowest sums (representing the least and most complex tests) are found at the extremes.

Guttman (1969) also showed that any such set of n tests will possess the following regression properties: (1) when the complexity order is given as $t_j<t_h<t_k$, the correlation between t_j and t_k when t_h is partialled out is zero. In other words, the partial correlation $r_{jk\bullet h}=0$, since the partialling effect results in a complete lack of common qualities remaining between t_j and t_k; (2) when regressing t_j in the remaining tests, for example, $\hat{t}_j=a+b_1t_1+\dots+b_{j-1}t_{j-1}+b_{j+1}t_{j+1}+\dots+b_nt_n$, the set of multiple regression coefficients (b's) retains a pattern by which those b's associated with tests closest to t_j (e.g., b_{j-1} and b_{j+1}) are larger than those which are furthest from t_j; and (3) the multiple correlations of $R_{j.1\dots(j-1)(j+1)\dots n}$ which are associated with tests of intermediate complexity are higher than those associated with the most and least complex tests.

Under the Quasi-Simplex model, any test score (T_j) is assumed as being composed of an underlying Perfect-Simplex score η_j and an error score (e_j) whose relationship can be expressed as:

$$T_j=\eta_j+e_j, \qquad j=1,\ 2,\ \dots,\ n. \tag{1}$$

where the variables η_j form a Perfect Simplex structure when **(1)** obeys three laws of deviation of the e_j (e.g., $\rho_{e_jT_k}=0,\ \ j\neq k;\ \rho_{e_j\eta_k}=0,\ \ j,\ k=1,\ 2,\ \dots,\ n;\ \rho_{e_je_k}=0,\ \ j\neq k$). In terms of the orthogonal common-factors, η_j is the linear combination of the first j common-factors (C), for example, $\eta_j=C_1+C_2+\dots+C_j$ ($j=1,\ 2,\ \dots,\ n$). Thus, **(1)** could be expanded as:

$$\begin{array}{ll}
T_1=C_1 & +e_1 \\
T_2=C_1+C_2 & +e_2 \\
T_3=C_1+C_2+C_3 & +e_3 \\
\vdots \quad\quad \vdots & \vdots \\
T_{n-1}=C_1+C_2+\dots+C_{n-1} & +e_{n-1} \\
T_n=C_1+C_2+\dots\dots\dots\dots+C_n & +e_n.
\end{array} \tag{2}$$

Moreover, **(2)** implies $r_{\eta_j\eta_k\bullet\eta_h}=0$, a partial correlation which occurs because the effects of the same common-factors are removed from both η_j and η_k. In addition, the set of variables η_j also produces the same regression properties and matrix pattern as those yielded by a set of Perfect-Simplex model tests.

As previously noted, items for each ILPS test set were divided into four subtests, each measuring a separate cognitive process associated with subject knowledge, understanding, application or integration; it was also assumed that the four subtests possessed a simple order of learning complexity from least to most complex. Since the four subtests within each subject area are of the same kind, the principles of the Simplex Theory may be used to determine if the four subtests fit a Perfect or Quasi-Perfect Simplex model. Such an examination is also needed to assess the extent to which consistency can be established between the results of a panel study and statistical methodology.

2. Analyses for Homogeneity and Unidimensionality

As stated earlier, test item sets must satisfy the criteria of unidimensionality prior to calibration via an IRT model. Statistically speaking, test item homogeneity is a required characteristic of any unidimensional test, and therefore ILPS tests must be screened in order to eliminate heterogeneous items; all remaining items must still be subjected to further analyses for homogeneity and unidimensionality.

A. Principal Component Analysis (Harman, 1976)

The primary concept of this analysis type is that, given a set of *n* items, the performance of individual items can be expressed as a linear composite of n uncorrelated common-factors. This type of analysis can be expressed as: $Z_i=\sum_{j=1}^{n}a_{ij}F_j=a_{i1}F_1+a_{i2}F_2+...+a_{n}F_{n}$, where a_{ij} is the factor loading of item *i* on factor *j*. Principal Component Analysis has as its underlying technique the computation of the eigenvalue (λ) of the matrix (R) of item intercorrelations via the characteristic equation $|R-\lambda I|=0$. In addition, the computation process must meet the criterion that the eigenvalue associated with the first factor ($\lambda_1=\sum_{i=1}^{n}a_{i1}^2$) should be larger than those associated with the remaining $n-1$ factors ($\lambda_j=\sum_{i=1}^{n}a_{ij}^2$, $j=2, 3, ..., n$). In other words, this criterion allows the first factor F_1 to extract the highest percentage variance, which is defined as λ_1/number of items. Since the first factor holds this property of maximum variance (including large loadings) from most, if not all, of the *n* items being analyzed, a practical approach is to measure item homogeneity in terms of the magnitude of the first factor loading. For example, items whose $a_{i1}<0.30$ are considered heterogeneous relative to those with an $a_{i1}\geq0.30$. For the present study, we adopted $a_{i1}\geq0.30$ as the critical factor loading when selecting homogeneous items for cluster analysis.

B. Cluster Analysis

Cluster analysis evolved from methodology used to explore the classification of fauna as part of the Linnean Taxonomic System. Essentially, this analysis is a scheme for grouping *n* unclassified objects into a small number of distinct clusters. This classification process uses predetermined criteria such that objects within any cluster hold greater similarity.

Despite the great proliferation of clustering techniques (see Everitt, 1980, for a full review), for our purposes we will limit our summary of the underlying principles of hierarchical clustering to the following: given a set of *n* objects, each measured by *p* variables (which constitute a frame of reference for establishing clusters), one must choose between forming a $n\times n$ matrix of either similarity or dissimilarity; in other words, the matrix elements may consist of association measures or distance measures of the *p* variables. Regardless of the similarity/dissimilarity choice, the $n\times n$ matrix serves as input data for the creation of a dendrogram – a two-dimensional diagram which displays the groups that are formed, as well as the associated distance coefficients at each fused stage. For example, if the underlying structure of *n* objects consists of two distinct clusters, such a structure can be visualized as a dendrogram similar to that shown in Panel A of Fig. 1. The dendrogram in Panel B, however, indicates that the data lacks cluster structure.

To investigate whether or not an ILPS test item set is homogeneous, for this study we chose a single-linkage method subsumed under hierarchical agglomerative techniques to analyze the input data of the inter-item correlation matrix. This decision was made in accordance with the argument presented by Jardin & Sibson (1971) that this method is the only one capable of satisfying certain mathematical conditions which they believe are required when transforming a measure of (dis)similarity into a hierarchical dendrogram. In addition, in accordance with Cormack's argument (Cormack, 1971), we chose to use cluster analysis for dissecting groups of homogeneous objects – in other words, to test the hypothesis that a dendrogram associated with any ILPS test item set will fail to display a group structure, which of itself is considered an indication of homogeneity.

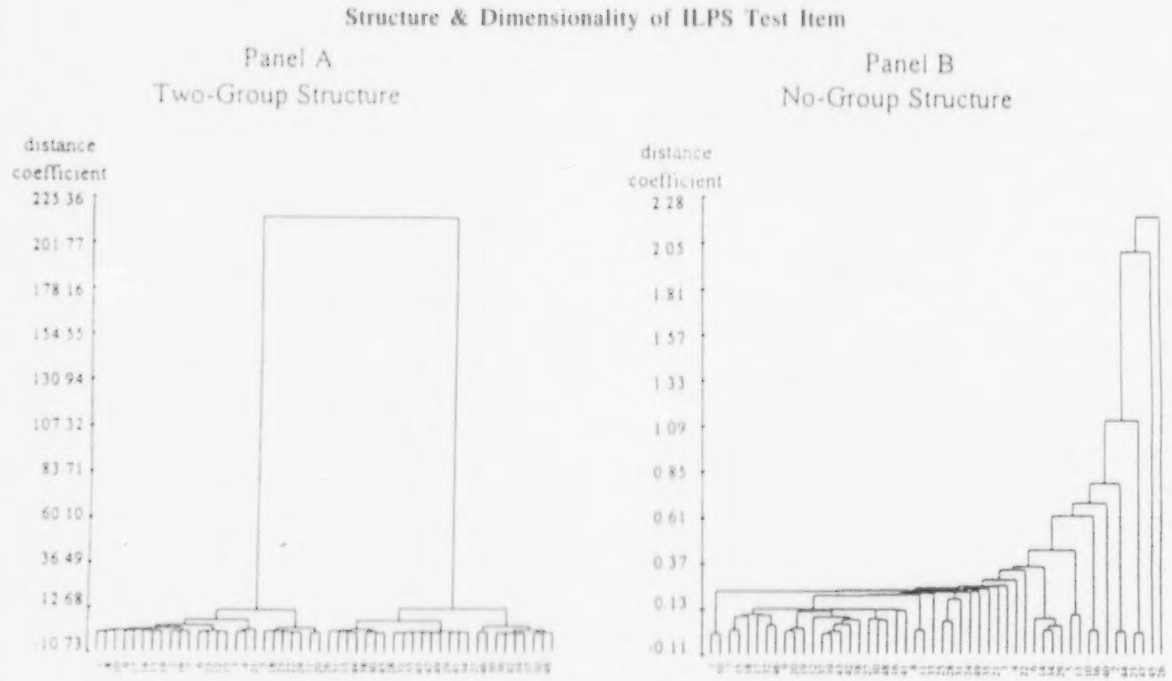


Fig. 1. Dendrograms representing a two-group structure and a no-group structure. (From Everitt, 1980: 87 and 90.)

C. Unidimensionality Analysis

According to item response theory (Lord & Novick, 1968; Lord, 1980), models are established via the use of an item response function to describe to what degree an examinee's response is dependent on his or her ability. The ogive model in **(3)** represents one form of item response function, one which states that the probability of a correct response to a dichotomously scored item g, $P_g(\theta)$ or $P_g(U_g=1|\theta)$ increases as ability θ increases, where θ is a one-dimensional latent variable

$$P_g(\theta) = Prob(U_g = 1|\theta)$$

$$= \int_{-\infty}^{a_g(\theta-b_g)} \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt = \Phi[a_g(\theta-b_g)], \quad \textbf{(3)}$$

where

$$\begin{cases} b_g = P_g(b_g) = 0.50 = \text{item difficulty}, \\ a_g = \sqrt{2\pi} P_g'(b_g) = \text{item discrimination}. \end{cases}$$

Formula **(3)** also serves as an item-ability regression function (the regression of U_g on θ) since $P_g(\theta)= E(U_g| \theta)$. A regression function – including its inflection point as well as the slope at that point – remains unchanged regardless of the frequency distribution of ability in the group being tested. Since the item parameters b_g and a_g are respectively related to the inflection point and the slope of the ogive, they serve as invariant item parameters regardless of which group is under analysis. It appears that, relative to its classical counterpart, IRT serves as a better response to the problem of securing item parameters with invariance properties. However, its legitimacy is dependent on the model successfully meeting an assumption of unidimensionality.

The meaning of an unidimensionality test may be clarified in terms of two mathematically equivalent statements shown as **(4)** and **(5)**. Let $\mathbf{u}=(u_1, u_2, ..., u_n)$ represent an examinee's binary responses to a set of n test items; **(4)** – which represents Lazarsfeld's assumption of local independence (Lazarsfeld & Henry, 1968) – states that for a fixed value of θ, an examinee's probability of success on all n items equals the product of the separate probabilities of success on individual items.

$$g(\mathbf{u}|\theta) = g(u_1, u_2, \ldots, u_n|\theta)$$

$$= \prod_{g=1}^{n} f_g(u_g|\theta) = \prod_{g=1}^{n} Prob(U_g = u_g|\theta)$$

$$= \prod_{g=1}^{n} [P_g(\theta)]^{u_g}[1 - P_g(\theta)]^{1-u_g}, \qquad \textbf{(4)}$$

where

$$f_g(u_g|\theta) \equiv \begin{cases} P_g & \text{if } u_g = 1\,, \\ 1 - P_g & \text{if } u_g = 0\,. \end{cases}$$

Equivalently, the viewpoint of unidimensionality taken by **(5)** is that the marginal distribution $g(\mathbf{u})$ of $\mathbf{U}=(U_1, U_2, \ldots, U_n)$ for an examinee chosen at random can be expressed as the conditional distribution of **(4)** and a prior distribution $f(\theta)$ for the random variable of latent ability Θ.

$$g(\mathbf{u}) = \int_{-\infty}^{\infty} g(u|\theta)f(\theta)d\theta \qquad \text{for all } \mathbf{u}$$

$$= \int_{-\infty}^{\infty} \left\{ \prod_{g=1}^{n} [P_g(\theta)]^{u_g}[1 - P_g(\theta)]^{1-u_g} \right\} f(\theta)d\theta\,. \quad \mathbf{(5)}$$

Lord & Novick (1968) and Lord (1980) has pointed out that if θ is normally distributed in the group tested – that is, $f(\theta)=\varphi(\theta)$ in **(5)** – then it is possible to interpret unidimensionality from the single common-factor model. In this case, θ acts as the latent trait which underlies performance among test items, which is, by definition, unidimensionality. However, the absence of a statistical significance test for unidimensionality as defined in **(4)** or **(5)** forces a search for substitute procedures. Two such procedures have been proposed for practical purposes, both of them employing a comparison of latent roots extracted from data matrices of item intercorrelations. For example, one can treat data as arising from one-dimensional latent space if: (1) the first latent root is at least five times as large as the second, and the second is not substantially larger than any of the others (Lord, 1980); or (2) if the percentage variance of the first factor (defined as $\frac{\lambda_1}{\text{number of items}}$) is over 20% (Reckase, 1979). Generally speaking, these two unrefined procedures are only rules of thumb, that is, they are only capable of indicating the 'degree' to which a set of test items departs from unidimensionality.

In view of this great need for a significance test for unidimensionality, Stout (1987, 1990) derived the following equation for testing the hypothesis of unidimensionality of the latent space.

$$P(\mathbf{u}) = \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} P(\mathbf{u}|\theta)dF(\theta)\,. \quad \mathbf{(6)}$$

(6) serves as a nonparametric and multidimensional latent trait model, since $P_g(\theta)$ is capable of taking all functional forms other than a normal ogive, and a vector of latent space is assumed for abilities such as $\theta=(\theta_1, \theta_2, \ldots, \theta_k)$. After taking into consideration that test items are inherently multiply determined, Stout set out to determine the potential for a set of test items to hold to an assumption of 'essential unidimensionality' – the existence of one (and only one) 'dominant' factor. In other words, Stout based the statistical index used to assess the departure from unidimensionality on a less restrictive assumption, namely 'essential local independence,' defined as:

$$\frac{1}{n(n-1)} \sum_{1 \le i \ne j \le n} |Cov(U_i\,, U_j|\theta)| \approx 0\,, \quad \mathbf{(7)}$$

where n is test length, that is, the conditional covariances on the average approach zero. This principle implies that examinees with approximately equal test scores on a reasonably long test should have equal ability when that test has a single dominant dimension (d=1).

Stout's formula tests H_0: d=1 v.s. H_1: d>1, following the empirical variant of **(7)** as follows:

$$S_{M\,.\,n} \equiv \frac{1}{M(M-1)} \sum_{1 \le i \ne j \le M} Cov(U_i\,, U_j|Y_p) \approx 0\,, \quad \mathbf{(8)}$$

where

$$\begin{cases} M: \text{length of an assessment subtest} \\ Y_p: \text{proportion right on a long partitioning} \\ \qquad \text{subtest with } (n-M) \text{ items.} \end{cases}$$

The procedure underlying **(8)** is the division of a test composed of n items into one assessment subtest with M highly homogeneous items, after which a second subtest is partitioned using the remaining (n–M) items. When test dimensionality d=1, both subtests are said to measure the same dimension or construct. On the other hand, when d>1, the partitioning subtest is said to contain items that measure dimensions which were not measured by the assessment subtest.

Responses to the items in these subtests are used to assess the test's overall unidimensionality and to divide examinees into K groups. As shown by Stout (1987: 394), for examinees in any subgroup k, their responses to the M items of the assessment subtest are used to compute the usual score variance estimate as well as the unidimensional variance estimate. When d=1 the difference between the two estimates is small; when d>1, the difference is much larger. Stout's statistic for unidimensionality is formed by summing the normalized differences across all K subgroups. In addition, he also proposed a correcting statistic for shorter tests in order to control two sources of bias resulting from variability in (1) the ability of examinees, and (2) item difficulty.

Regarding the unidimensionality analysis, for the present study we employed both the traditional rules of thumb and Stout's testing statistics to examine the unidimensionality of the seventeen ILPS tests examined (see Table 2). In addition, we examined the extent to which similar results were attained by both procedures.

Both subtests so named are due to the fact that the responses on them are respectively used to assess the test's unidimensionality and to partition examinees into *K* groups. As shown by Stout (1987: 394), for examinees in any subgroup *k*, their responses on the *M* items of the assessment subtest are used to compute the usual score variance estimate and the unidimensional variance estimate. When $d=1$, the difference value between both estimates is small; when $d>1$, the value is large. Stout's statistic for unidimensionality is formed by summing over the normalized differences across all *K* subgroups. In addition, Stout also proposed a corrected statistic to reduce two sources of bias resulting from the variabilities in examinee's ability and in item difficulty when the length of a test is not long.

With respect to the unidimensionality analysis, this study will employ both the traditional rules of thumb and Stout's testing statistic to examine whether unidimensionality holds for all the 17 tests of ILPS (see Table 2). Moreover, this study also examines the extent to which similar results are attained by both procedures.

III. Data Resources

1. Testing Materials

The original NSC-commissioned research project focused on science achievement assessment for students in grades 6, 9, and 12. The five sub-projects resulted in ILPS test sets being created for each of the five subject areas across the three grade levels, with two test sets each for biology, earth science, and physics and single test sets for chemistry and science process skills (SPS). In addition, to conform to the national curricula established for grades 6 and 9, items randomly chosen from the item pools of the five science subjects were used to create two "natural science" tests. In all, Shin and Cheng's work resulted in the creation of 26 tests. Table 1 lists the content areas which the ILPS sets measure. Form A of the chemistry test was specifically designed to measure a single content area (Acids and Bases); in all other cases, the combined subject tests measure two or more content areas.

2. Samples

For the present study we adopted a two-stage sampling frame similar to that described in the IAEP Sampling Manual (1990). Each target population (corresponding to grades 6, 9, and 12) constituted a universal list of schools in a district which includes Taipei city and county. First-stage sampling units consisted of the school numbers 11, 9, and 12 for grades 6, 9 and 12, respectively; second-stage units consisted of individual classes within the three schools being sampled. (It should be noted that all senior high school classes consisting of students majoring in the social sciences were excluded). We then randomly chose class samples by means of balancing such factors as school quality and student ability. The number

Table 1. Content Areas Measured by ILPS Test Forms, Their Subject Matter and Grade Levels

	Content Area		
Subject	Form A	Form B	Grade
Biology	Structure and Function of Plants	Heredity	6, 9, 12
Earth Science	Meteorology	Astronomy	6, 9, 12
Physics	Mechanics/Optics	Electromagnetism	6
	Mechanics/Motion	Electromagnetism	9
	Mechanics	Electromagnetism	12
Chemistry	Acids and Bases		6, 9, 12
Science Process Skills	Communication/Interpretation		6, 9, 12
Natural Science	Structure and Function of Plants Meteorology/Astronomy Mechanics/Electromagnetism Acids and Bases		6, 9

of students sampled was over 7,000 for grade 6 and over 9,000 each for grades 9 and 12.

The assignment procedure also entailed both independent and dependent measures of the subject areas under investigation. For example, identical groups of grade 12 students took chemistry and SPS tests, but independent samples were assigned for assessing achievement in biology, earth science, and physics. For grades 6 and 9, independent samples were taken for assessing biology, earth science, and physics achievement while identical samples took the chemistry and natural science tests. Finally, all sampled students for grades 9 and 12 were assigned for the assessment of science process skills.

Table 2 presents sample size lists for the six subject areas across grades 6, 9, and 12; the table also presents the test lengths associated with each of the 26 test forms. As shown in columns 2, 7 and 12, sample sizes for five subject areas (minus science process skills) have very small ranges: 1787 to 1852, 2243 to 2327, and 2170 to 2394 for grades 6, 9 and 12, respectively. Columns 6, 11 and 16 list revised test lengths following the deletion of items having any format other than multiple choice. The ranges of the numbers of items across the five subject tests were much more broad: 26 to 80, 32 to 76, and 29 to 56 for grades 6, 9 and 12, respectively. The data matrix for each subject in each grade is composed of binary responses, and as described earlier, each matrix (17 in all) was subject to cluster and unidimensionality analyses. In contrast, since the requirement for the minimum number of cognitive levels needed for using the simplex model was met only by the biology test items, our complexity structure analysis was limited to the use of biology test data only.

IV. Data Analysis

1. Complexity Structure

As judged by a panel of experts, the biology items on the "A" forms for grades 6 and 9 were broken down into four subtests according to the distribution of the cognitive processes being tested. Table 3 shows the distributions for both forms, with T_1, T_2, T_3 and T_4 respectively representing the subtests corresponding to knowledge, understanding, application and integration.

Since the degree of learning complexity of the four subtests followed the hypothesized order of $T_1<T_2<T_3<T_4$, according to **(2)** the subtest scores can be described as:

$$T_1=C_1 \qquad +e_1$$

$$T_2=C_1+C_2 \qquad +e_2$$

$$T_3=C_1+C_2+C_3 \qquad +e_3$$

$$T_4=C_1+C_2+C_3+C_4 \quad +e_4.$$

In addition, the Simplex part variances (η_j) of the four subtest scores can be described as:

$$\sigma^2_{\eta_1} = \sigma^2_{C_1}$$

$$\sigma^2_{\eta_2} = \sigma^2_{C_1} + \sigma^2_{C_2}$$

$$\sigma^2_{\eta_3} = \sigma^2_{C_1} + \sigma^2_{C_2} + \sigma^2_{C_3}$$

$$\sigma^2_{\eta_4} = \sigma^2_{C_1} + \sigma^2_{C_2} + \sigma^2_{C_3} + \sigma^2_{C_4}.$$

Table 2. Sample Sizes and Test Lengths Across Six Subject Areas and Three Grade Levels

	Grade 12					Grade 9					Grade 6				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Test Form		Original	Revised		Test Form		Original	Revised		Test Form		Original	Revised
	Sample	Length		Test	Test	Sample	Length		Test	Test	Sample	Length		Test	Test
Subject	Size	A	B	Length	Length	Size	A	B	Length	Length	Size	A	B	Length	Length
Biology	1826	40	40	80	80	2286	38	38	76	76	2213	28	28	56	56
Earth Science	1796	30	30	60	60	2327	30	30	60	60	2394	25	24	49	49
Physics	1787	18	18	36	26	2302	38	29	67	36	2170	35	21	56	41
Chemistry	1872[1]	35		35	35	2271[1]	43		43	43	2391[1]	33		33	33
SPS[2]	1852[1]	35		35	31	9171	37		37	32	9132	32		32	29
Natural Science						2243[1]	36		36	36	2390[1]	32		32	32

[1] indicates identical groups of students

[2] indicates Science Process Skill

Table 3. Distribution of Cognitive Processes Measured by Grades 6 and 9 Biology Test Items

	Grade 9 (Form A)		Grade 6 (Form A)	
Cognitive Process	n_i	Item Number	n_i	Item Number
T_1: Knowledge	2	1 25	4	1 2 6 14
T_2: Understanding	13	4 7 14-19 22 30-32 35	14	4 5 7-10 12 19-21 24-27
T_3: Application	12	2 5 6 8 9 12 13 20 23 24 36 37	3	5 13 28
T_4: Integration	11	3 10 11 21 26-29 33 34 38	7	11 15-18 22 23
n	40		28	

Clearly, η_j variances increase with subtest rank order, that is, $\sigma^2_{\tilde{\eta}_1} < \sigma^2_{\tilde{\eta}_2} < \sigma^2_{\tilde{\eta}_3} < \sigma^2_{\tilde{\eta}_4}$, and the correlation between η_j and η_k is the ratio of σ_{η_j} to σ_{η_k}, $j \leq k$. Guttman (1969) used this ratio to define the Perfect Simplex matrix of intercorrelation according to the Quasi-Simplex model (Jöreskog, 1970). LISREL-8 software (1993) has made it possible to estimate η intercorrelations by imposing certain identification conditions on the model's parameters. For the present study we used the LISREL-8 program to measure the goodness of fit of the Quasi-Simplex model to the $\mathrm{R}^{(T)}$ data – that is, the correlation matrix of the subtest scores on T_1 to T_4. It follows that if $\mathrm{R}^{(T)}$ fits the model, the η correlation matrix ($\mathrm{R}^{(\eta)}$) could be used to both compute the complexity coefficients and investigate the following features – all of which are characteristic of a Perfect Simplex structure:

(1) As mentioned in Section II of this paper, $\mathrm{R}^{(\eta)}$ maintains the general northeast-southwest characteristic;

(2) The partial correlations $r_{14\cdot3}$, $r_{13\cdot2}$, $r_{24\cdot3}$ should approach zero;

(3) When predicting a single subtest in terms of its three associated subtests, the four multiple correlations should display a border effect and the regression weights should show a neighboring effect. The border effect refers to the idea that the values of $R_{1.234}$ and $R_{4.123}$ are lower than those of $R_{2.134}$ and $R_{3.124}$. The neighboring effect refers to the following comparisons:

   (i) b_2 is higher than b_3 and b_4 in the equation $\hat{\eta}_1 = b_2\eta_2 + b_3\eta_3 + b_4\eta_4$;

   (ii) b_3 is higher than b_2 and b_1 in the equation $\hat{\eta}_4 = b_1\eta_1 + b_2\eta_2 + b_3\eta_3$;

   (iii) b_4 is lower than b_1 and b_3 in the equation $\hat{\eta}_2 = b_1\eta_1 + b_3\eta_3 + b_4\eta_4$; and

   (iv) b_1 is lower than b_2 and b_4 in the equation $\hat{\eta}_3 = b_1\eta_1 + b_2\eta_2 + b_4\eta_4$.

2. Principal Component Analysis for Homogeneity and Unidimensionality

The input data required for the principal component analysis consists of the matrix of item intercorrelations. The measure of correlation between individual items is based on the tetrachoric correlation coefficient (see Lord & Novick, 1968: 345; Lin, 1992) – a choice supported by the assumptions underlying the normal ogive of **(3)**, which is equivalent to **(9)**:

$$p_g(\theta) \equiv E(U_g|\theta) \equiv Prob(U_g = 1|\theta)$$

$$= \Phi\left(\frac{\mu_{g|\theta} - \gamma_g}{\sigma_{g|\theta}}\right) = Prob(Y_g > \gamma_g|\theta)\,. \qquad \textbf{(9)}$$

where Y_g is a hypothetical trait determining whether or not examinees answer item g correctly and where γ_g is a constant which characterizes that item. Formula **(9)** also indicates that, for any given item g, the unobservable continuous quantity Y_g is dichotomized at γ_g. When $Y_g \geq \gamma_g$, its observed binary quantity $U_g=1$; when $Y_g < \gamma_g$, then $U_g=0$. This hypothetical relationship between U_g and θ in $P_g(\theta)$ is illustrated in Lord & Novick (1968: 371).

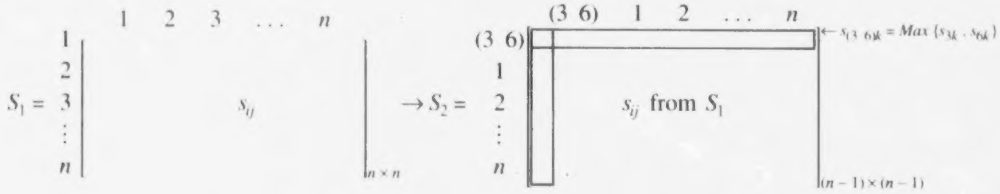
In other words, given a set of n items, the IRT assumes that the multivariate distribution of $(U_1, \ldots U_g, \ldots, U_n)$ may be the result of a multivariate normal distribution $(Y_1, \ldots Y_g, \ldots, Y_n)$ after dichotomizing each Y-variable at some point γ. Subsequently, the underlying statistical problem in terms of any pair of items i and j is how to infer the product moment correlation $\rho(Y_i, Y_j)$ from the tetrachoric correlation (U_i, U_j), since the latter measure is used to correlate two artificially dichotomized variables that have a bivariate normal distribution. For this reason, we obtained the matrix of tetrachoric item intercorrelation ($\mathbf{R}_{tet}$) for each of the seventeen data sets listed in Table 2. Each $\mathbf{R}_{tet}$ was subjected to the principal component analysis, with $a_{i1}F_1 \geq 0.30$ used as the criterion for eliminating heterogeneous items from each data set.

For those remaining homogeneous items, we also computed the corresponding $\mathbf{R}_{tet}$ matrices, with each new $\mathbf{R}_{tet}$ once again being subjected to a principal component analysis for extracting eigenvalues by solving $|\mathbf{R}_{tet}-\lambda\mathbf{I}|=0$. The two rules of thumb proposed by Lord (1980) and Reckase (1979) were then used to compare the magnitudes of each eigenvalue as part of a unidimensionality analysis.

3. Homogeneous Structure via Clustering

Using the single linkage method, dendrograms were obtained for each data set following principal component analysis. According to this method, input data consisted of the matrix of similarity measures between items – namely, $\mathbf{S}_1$. Here we used $\mathbf{R}_{tet}$ as $\mathbf{S}_1$ (that is, $\mathbf{S}_1=\{s_{ij}=r_{tet}(i,\ j)\}$, $i,\ j=1,\ 2,\ \ldots,\ n$) for comparing results based on the same measurement units.

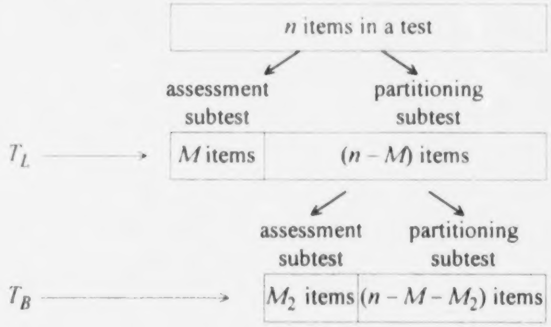
The single linkage procedure consists of a series of $(n-1)$ fusion stages. During the procedure's first stage, the two items $(i,\ j)$ with the largest s_{ij} $(i\neq j)$ in the $\mathbf{S}_1$ matrix are fused to form a group because they are the most similar item pair. To illustrate, let items 3 and 6 serve as one group. At stage two, a new similarity matrix $\mathbf{S}_2$ with the order $(n-1)$ by $(n-1)$ is formed by treating items (3, 6) as a group; similarity measures between group (3, 6) and the remaining $(n-2)$ items are obtained under the condition of $s_{(3,\ 6)k}=\text{Max}\{s_{3k},\ s_{6k}\}$ $(k\neq 3,\ 6)$. In other words, as shown in the diagram below, $\mathbf{S}_2$ presents group-individual as well as interindividual item similarities.



Next, the largest $\mathbf{S}_2$ entry is searched for the purpose of forming a second group, with the process described above being followed once again until $\mathbf{S}_{n-1}$ is formed at the final stage. During that final stage, a conclusive fusion of two groups takes place, with the final result being a complete dendrogram showing all fusions made in each successive stage. The dendrograms are then examined in order to check for the emergence of distinct clusters. For this study we used a dendrogram similar to that shown in Panel B of Fig. 1 to indicate a homogeneous structure of test items.

4. Stout's Unidimensionality Test

Stout's statistic for unidimensionality which underlies **(8)** is represented by the formula $T=\dfrac{T_L-T_B}{\sqrt{2}}$, whose asymptotic distribution is $N(0,\ 1)$. T_B compensates for the biases of item difficulty and examinee variability which occur in T_L for shorter tests. As shown in the following diagram, computation procedures for T_L and T_B differ in how different assessment subtest items are used.



Both assessment subtests have identical numbers of items $(M=M_2)$ and similar item difficulty distributions. However, to enhance the power of the statistical test when $d>1$, M items are selected to serve a nonhomogeneous role in comparison with the $(n-M)$ partitioning items, while M_2 items serve a homogeneous role to the $(n-M-M_2)$ partitioning items. With the exception of this single difference, the computation process is the same for T_L and T_B. The following serves as a summary of the main steps taken for the computation of T_L for a given binary data $[0,\ 1]_{J\times n}$ with $J\leq 2000$ examinees and $n<80$ items. (Those interested in reading a detailed description of the steps involved can find them in Stout (1987: 592-595))

(1) J examinees are randomly assigned to groups A and B in a ratio of 1:3 for the purpose of dividing the raw data matrix $[0,\ 1]_{J\times n}$ into matrices of $[0,\ 1]_{J_A\times n}$ and $[0,\ 1]_{J_B\times n}$.

(2) The data matrix $[0,\ 1]_{J_A\times n}$ is used to obtain M items with the largest loadings in the bi-polar factor; these constitute the most homogeneous

set of assessment items.

(3) The data matrix $[0, 1]_{J_B \times (n-M)}$ is used to separate J_B examinees into k groups based on the $(n-M)$ subtest scores such that examinees within any group k will have the same test score.

(4) For a fixed group of J_k examinees, associated responses of J_k to M items (as shown below) are used to calculate the score variance estimate $\hat{\sigma}_k^2$ in **(10)**, the unidimensionality variance estimate $\hat{\sigma}_{U,k}^2$ in **(11)**, and the normalizing constant S_k^2 in **(12)**;

	Item						
Examinee	1	2	.	.	M	Score	Statistic
1	U_{11}	.	.	.	U_{1M}	$Y_1^{(k)}$	
2	U_{21}				U_{2M}	$Y_2^{(k)}$	
.	.				.	.	$[\hat{\sigma}_k^2, (\hat{\sigma}_k^4, \hat{\mu}_{4,k})]$
.	.				.	.	
.	.				.	.	
J_k	U_{J1}	.	.	.	U_{JM}	$Y_j^{(k)}$	
Proportion	$\hat{p}_1^{(k)}$	.	.	.	$\hat{p}_M^{(k)}$		
Statistic	$[\hat{\sigma}_{U,k}^2, (\hat{\delta}_{4,k}, M^4)]$						

$$\hat{\sigma}_k^2 = \sum_{j=1}^{J_k} \frac{(Y_j^{(k)} - \overline{Y}^{(k)})^2}{J_k}, \tag{10}$$

where

$$Y_j^{(k)} = \sum_{i=1}^{M} \frac{U_{ijk}}{M}, \quad \overline{Y}^{(k)} = \sum_{j=1}^{J_k} \frac{Y_j^{(k)}}{J_k};$$

$$\hat{\sigma}_{U,k}^2 = \sum_{i=1}^{M} \frac{\hat{p}_i^{(k)}(1-\hat{p}_i^{(k)})}{M^2}, \tag{11}$$

where

$$\hat{p}_i^{(k)} = \sum_{j=1}^{J_k} \frac{U_{ijk}}{J_k};$$

$$S_k^2 = \frac{(\hat{\mu}_{4,k} - \hat{\sigma}_k^4) + \dfrac{\hat{\delta}_{4,k}}{M^4} + 2\left(\dfrac{(\hat{\mu}_{4,k} - \hat{\sigma}_k^4)\,\hat{\delta}_{4,k}}{M^4}\right)^{1/2}}{J_k}; \tag{12}$$

where

$$\hat{\mu}_{4,k} = \sum_{j=1}^{J_k} \frac{(Y_j^{(k)} - \overline{Y}^{(k)})^4}{J_k},$$

$$\hat{\delta}_{4,k} = \sum_{i=1}^{M} \hat{p}_i^{(k)}(1-\hat{p}_i^{(k)})(1-2\hat{p}_i^{(k)})^2.$$

(5) Statistic **(10)**, **(11)** and **(12)** are computed for each k group to obtain

$$T_L = \frac{1}{K^{1/2}} \sum_{k=1}^{K} \left| \frac{\hat{\sigma}_k^2 - \hat{\sigma}_{U,k}^2}{S_k} \right|.$$

(6) T_B is computed according to steps 2-5 based on the data matrix $[0, 1]_{J_{B \times (n-M)}}$. However, as previously mentioned, M_2 items are specifically constructed to be similar to M items in terms of item difficulty distribution and to be homogeneous to the $(n-M-M_2)$ partitioning subtest items.

(7) Calculate $T=(T_L-T_B)/\sqrt{2}$ and reject H_0: $d=1$ if $T>Z_\alpha$, where $Z \sim N(0, 1)$ and α is the significance level.

For the present research, test data sets were subjected to both traditional unidimensionality analysis and Stout's Unidimensionality test. Since test length (n) varied according to data set, we established M in proportion to n. As sample size (J) consisted of approximately 2,000 subjects, the previously mentioned 1:3 ratio was used to separate J examinees into J_A and J_B groups. In addition, tetrachoric item intercorrelations based on data $[0, 1]_{J_A \times n}$ were used during Step 2 for the selection of M items. Results were compared with those yielded by traditional unidimensionality analysis to check the validity of the "rules of thumb" in examining test unidimensionality.

V. Results and Discussion

1. Complexity Structure

Table 4 presents the results of our complexity structure analysis on the four Form A biology subtests for grades 6 and 9. A goodness of fit test performed on the grade 9 data set $R^{(T)}$ showed $\chi^2=0.22$ ($P=0.64$), indicating that $T_1 \sim T_4$ complied with the Quasi-Simplex model. The resulting $R^{(\eta)}$ pattern maintains an approximate northeast-southwest character in two respects: (1) correlations decrease as they move to the left or right away from the main diagonal; and (2) the two lowest column sums (3.00 and 3.61) are associated with the least and most complex subtests η_1 and η_4, whereas the two highest totals (3.65 and 3.64) are associated with the two intermediate complexity subtests, η_2 and η_3. We found that the values of the three partial correlations approached zero – that is, $r_{14\cdot3}=0.004$, $r_{13\cdot2}=0.003$, and $r_{24\cdot3}=0.003$. The results also revealed that all four Form A biology subtests for grade 9 displayed the border effect, since $R_{1.234}(=0.67)$ and $R_{4.123}(=0.97)$ were lower than the $R_{2.134}$ and $R_{3.124}$

Table 4. Results of Complexity Structure Analyses on Four Form A Biology Subtests for Grades 6 and 9

		Cognitive Level		Correlations among Four Subtests				Multiple-Regression Weights (b's)				Multiple-Correlations (R's)	Complexity Loading
				T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4		
	$R^{(T)}$	Knowledge	T_1	1.00	0.47	0.44	0.42		0.24	0.20	0.16	0.51	0.42
		Understanding	T_2	0.47	1.00	0.66	0.64	0.15		0.39	0.35	0.74	0.91
		Application	T_3	0.44	0.66	1.00	0.58	0.14	0.43		0.25	0.70	0.95
		Integration	T_4	0.42	0.64	0.58	1.00	0.11	0.41	0.26		0.68	1.00
Form A			sum	2.33	2.76	2.68	2.64						
(Grade 9)				η_1	η_2	η_3	η_4	η_1	η_2	η_3	η_4		
	$R^{(\eta)}$	Knowledge	η_1	1.00	0.67	0.67	0.66		0.84	-0.17	0.00	0.67	0.66
		Understanding	η_2	0.67	1.00	1.00	0.98	-0.03		1.03	0.01	1.00	0.98
		Application	η_3	0.67	1.00	1.00	0.97	0.01	1.49		-0.50	1.00	0.98
		Integration	η_4	0.66	0.98	0.97	1.00	0.00	-0.02	0.99		0.97	1.00
			sum	3.00	3.65	3.64	3.61						
				T_1	T_2	T_4	T_3	T_1	T_2	T_4	T_3		
	$R^{(T)}$	Knowledge	T_1	1.00	0.26	0.20	0.10		0.21	0.11	0.04	0.29	0.10
		Understanding	T_2	0.26	1.00	0.38	0.22	0.19		0.32	0.15	0.45	0.40
		Integration	T_4	0.20	0.38	1.00	0.17	0.10	0.33		0.09	0.40	0.53
		Application	T_3	0.10	0.22	0.17	1.00	0.04	0.17	0.10		0.24	1.00
Form A			sum	1.56	1.86	1.75	1.50						
(Grade 6)				η_1	η_2	η_4	η_3	η_1	η_2	η_4	η_3		
	$R^{(\eta)}$	Knowledge	η_1	1.00	0.51	0.49	0.29		0.59	-0.09	0.01	0.51	0.29
		Understanding	η_2	0.51	1.00	0.97	0.56	0.05		0.95	0.00	0.97	0.57
		Integration	η_4	0.49	0.97	1.00	0.58	-0.01	0.94		0.05	0.97	0.59
		Application	η_3	0.29	0.56	0.58	1.00	0.01	-0.05	0.62		0.58	1.00
			sum	2.29	3.04	3.04	2.43						

figures associated with the two subtests of intermediate complexity. The neighboring effect was present as well: the regression weight values b_2 and b_3 were found to be the highest and b_4 and b_1 the lowest relative to their respective b's in corresponding equations. As Table 4 shows, the complexity loadings calculated for η_1~η_4 were 0.66, 0.98, 0.98 and 1.00, respectively, which reflects a trend towards increasing complexity. Differences in loading associated with subtests η_2~η_4 were found to be negligible; the complexity loading of η_1 was substantially lower than those of η_2~η_4.

A goodness of fit test on the grade 6 data set with the order of T_3 and T_4 reversed resulted in χ^2=0.21 (P=0.64). In other words, in the order T_1–T_2–T_4– T_3 the four subtests fit the Quasi-Simplex model. Results in support of this conclusion include: (1) the $R^{(\eta)}$ pattern maintains a northeast-southwest character; (2) the sums of the four columns are consistent with the features of the Perfect Simplex models in that the lowest totals (2.29 and 2.43) are associated with η_1 and η_3, while the highest totals (3.04 and 3.04) are associated with η_2 and η_4; (3) the values of the three partial correlations approach zero ($r_{14 \cdot 2}$=−0.022, $r_{13 \cdot 4}$=0.008, and $r_{13 \cdot 2}$=0.006); (4) the four resultant multiple correlation coefficients comply with our expected pattern – that is, $R_{1.234}$ (=0.51) and $R_{3.124}$ (=0.58) were found to be lower than $R_{2.134}$ (=0.97) and $R_{4.123}$ (=0.97); and (5) all b's displayed a neighboring effect in corresponding regression equations.

The complexity loadings for η_1–η_2–η_4–η_3 were calculated as 0.29, 0.57, 0.59 and 1.00, respectively (Table 4). The substantial difference between 0.59 and 1.00 indicates that the complexity order of subtests in terms of application and integration as judged by the panel of experts was incompatible with the order established by means of statistical methods. On the other hand, the substantial differences between 0.29 and 0.57 and between 0.57 and 1.00 suggest that the subjective judgment of the panel was the same as the conclusion arrived at statistically with respect to the complexity order of the knowing, understanding and integration subtests.

Table 5. First Common-Factor Loadings for Items From 10 ILPS Test Data Sets

	Biology						Chemistry						Science Process Skills			Physics						Natural Science						Eearth Science		
	G-9 (*n*=76)			G-6 (*n*=56)			G-9 (*n*=43)			G-6 (n=33)			G-9 (*n*=32)			G-12 (*n*=26)			G-9 (*n*=36)			G-9 (*n*=36)			G-6 (*n*=32)			G-9 (*n*=60)		
	(*n*'=70)			(*n*'=42)			(*n*'=41)			(*n*'=27)			(*n*'=29)			(*n*'=23)			(*n*'=29)			(*n*'=33)			(*n*'=28)			(*n*'=53)		
New Length	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	1	0.48	0.23	1	0.36	0.13	1	0.48	0.23	2	0.57	0.32	1	0.50	0.25	1	0.51	0.26	1	0.61	0.37	1	0.37	0.14	3	0.30	0.09	1	0.55	0.31
	2	0.57	0.33	3	0.30	0.09	2	0.64	0.41	3	0.56	0.32	2	0.67	0.45	3	0.49	0.24	2	0.70	0.48	2	0.46	0.22	4	0.41	0.16	2	0.69	0.47
	3	0.45	0.20	4	0.35	0.12	3	0.71	0.50	4	0.57	0.32	3	0.67	0.45	4	0.50	0.25	3	0.46	0.21	3	0.61	0.38	5	0.32	0.10	3	0.61	0.37
	5	0.60	0.36	5	0.30	0.09	4	0.55	0.30	5	0.55	0.30	4	0.70	0.49	5	0.44	0.20	7	0.58	0.33	4	0.53	0.29	6	0.38	0.15	4	0.60	0.36
	6	0.44	0.19	6	0.41	0.17	5	0.59	0.35	6	0.54	0.29	5	0.68	0.46	6	0.42	0.17	9	0.80	0.63	5	0.59	0.35	7	0.57	0.32	5	0.53	0.28
	7	0.53	0.28	7	0.38	0.14	6	0.45	0.20	7	0.65	0.42	6	0.48	0.23	7	0.57	0.33	12	0.83	0.68	6	0.44	0.19	8	0.66	0.43	6	0.38	0.14
	8	0.52	0.27	9	0.42	0.18	7	0.44	0.19	8	0.44	0.19	7	0.33	0.11	9	0.64	0.41	19	0.33	0.11	7	0.62	0.39	9	0.40	0.16	7	0.58	0.34
	12	0.52	0.27	12	0.30	0.09	8	0.71	0.50	9	0.68	0.46	8	0.67	0.45	10	0.50	0.25	20	0.78	0.62	9	0.41	0.17	10	0.47	0.22	8	0.60	0.36
	13	0.39	0.15	14	0.32	0.10	10	0.52	0.27	10	0.47	0.22	9	0.67	0.45	12	0.46	0.21	21	0.72	0.53	10	0.53	0.28	13	0.58	0.33	10	0.58	0.33
	14	0.47	0.22	16	0.55	0.30	11	0.70	0.49	11	0.61	0.37	10	0.64	0.41	13	0.72	0.52	23	0.38	0.14	11	0.57	0.33	14	0.45	0.20	11	0.61	0.37
	15	0.38	0.14	17	0.39	0.15	12	0.62	0.38	12	0.57	0.32	12	0.37	0.13	14	0.46	0.21	26	0.46	0.21	12	0.58	0.33	15	0.38	0.14	12	0.60	0.36
	16	0.65	0.42	18	0.30	0.09	13	0.69	0.48	14	0.33	0.11	13	0.64	0.41	15	0.36	0.13	30	0.53	0.28	14	0.42	0.18	16	0.48	0.23	13	0.63	0.40
	17	0.61	0.37	19	0.46	0.21	14	0.77	0.59	15	0.66	0.44	14	0.47	0.22	16	0.55	0.31	31	0.61	0.37	15	0.35	0.12	17	0.73	0.53	14	0.42	0.17
	18	0.55	0.30	20	0.41	0.17	16	0.73	0.54	16	0.69	0.47	15	0.68	0.47	17	0.57	0.33	36	0.45	0.20	16	0.61	0.38	18	0.73	0.53	15	0.50	0.25
	19	0.56	0.32	21	0.33	0.11	17	0.70	0.50	17	0.41	0.17	16	0.71	0.50	20	0.58	0.34	39	0.61	0.37	17	0.40	0.16	19	0.74	0.55	16	0.49	0.24
	20	0.34	0.12	23	0.41	0.17	18	0.52	0.27	18	0.43	0.18	17	0.76	0.57	21	0.45	0.20	40	0.71	0.51	18	0.41	0.17	20	0.61	0.37	17	0.70	0.49
	21	0.37	0.14	25	0.30	0.09	19	0.61	0.37	20	0.63	0.39	18	0.51	0.26	22	0.62	0.39	41	0.57	0.32	19	0.71	0.51	21	0.40	0.16	18	0.73	0.53
	22	0.58	0.34	26	0.41	0.17	20	0.58	0.34	21	0.62	0.38	19	0.75	0.56	23	0.55	0.30	42	0.47	0.22	20	0.70	0.49	22	0.73	0.53	19	0.59	0.34
	24	0.41	0.17	29	0.37	0.14	21	0.65	0.42	22	0.64	0.40	21	0.55	0.30	24	0.51	0.26	43	0.31	0.09	21	0.68	0.46	23	0.69	0.48	20	0.60	0.36
	25	0.63	0.40	31	0.39	0.15	22	0.56	0.31	23	0.70	0.49	22	0.55	0.30	25	0.51	0.26	44	0.71	0.51	22	0.60	0.36	24	0.34	0.12	21	0.67	0.44
	26	0.56	0.32	32	0.36	0.13	23	0.60	0.36	24	0.50	0.25	23	0.73	0.53	27	0.53	0.28	45	0.48	0.23	23	0.57	0.33	25	0.40	0.16	22	0.66	0.43
	27	0.70	0.49	33	0.42	0.18	24	0.53	0.28	26	0.61	0.38	24	0.36	0.13	28	0.38	0.14	52	0.70	0.49	24	0.61	0.37	26	0.37	0.14	23	0.73	0.54
	28	0.62	0.38	35	0.32	0.10	25	0.57	0.32	27	0.66	0.44	26	0.47	0.22	29	0.44	0.19	53	0.64	0.41	25	0.56	0.32	27	0.51	0.26	24	0.67	0.44
	29	0.55	0.31	36	0.46	0.21	26	0.59	0.35	28	0.70	0.48	27	0.35	0.12				54	0.64	0.40	26	0.67	0.44	28	0.49	0.24	25	0.64	0.41
	30	0.57	0.33	38	0.52	0.27	27	0.58	0.33	29	0.70	0.50	28	0.50	0.25				58	0.68	0.46	27	0.60	0.37	29	0.36	0.13	26	0.69	0.48
	31	0.44	0.19	39	0.50	0.25	28	0.65	0.42	30	0.71	0.51	29	0.51	0.26				60	0.35	0.12	28	0.69	0.47	30	0.33	0.11	27	0.68	0.46
	32	0.41	0.17	40	0.41	0.16	29	0.62	0.38	32	0.38	0.14	30	0.70	0.49				65	0.74	0.55	29	0.68	0.46	31	0.42	0.17	28	0.46	0.21
	33	0.45	0.20	41	0.41	0.17	30	0.49	0.24				31	0.49	0.24				66	0.67	0.45	30	0.57	0.32	32	0.50	0.25	29	0.47	0.22
	34	0.46	0.21	43	0.50	0.25	31	0.53	0.28				32	0.47	0.23				67	0.55	0.30	31	0.51	0.26				30	0.59	0.35
	35	0.43	0.18	44	0.31	0.09	32	0.39	0.15													32	0.40	0.16				31	0.63	0.39
	36	0.43	0.18	45	0.34	0.12	33	0.37	0.13													33	0.62	0.38				32	0.37	0.14
	37	0.37	0.14	46	0.71	0.50	34	0.72	0.52													34	0.53	0.28				33	0.50	0.25
	39	0.39	0.15	47	0.59	0.35	35	0.72	0.52													36	0.68	0.47				34	0.43	0.19
	40	0.68	0.47	48	0.58	0.34	36	0.49	0.24																			35	0.67	0.45
	41	0.51	0.26	49	0.60	0.36	37	0.77	0.59																			36	0.48	0.23
	42	0.38	0.15	50	0.35	0.12	38	0.53	0.28																			38	0.64	0.41
	43	0.49	0.24	51	0.35	0.12	39	0.63	0.40																			39	0.45	0.20
	44	0.45	0.20	52	0.57	0.33	40	0.64	0.41																			40	0.51	0.26
	45	0.63	0.40	53	0.50	0.25	41	0.46	0.21																			41	0.45	0.20
	46	0.56	0.31	54	0.65	0.42	42	0.63	0.39																			42	0.33	0.11
	47	0.39	0.15	55	0.67	0.44	43	0.61	0.37																			43	0.59	0.35
	48	0.40	0.16	56	0.57	0.32																						45	0.43	0.18
	49	0.67	0.44																									46	0.41	0.17
	50	0.34	0.12																									47	0.30	0.09
	51	0.67	0.45																									48	0.43	0.18
	52	0.52	0.27																									49	0.41	0.16
	53	0.45	0.20																									53	0.39	0.15
	54	0.53	0.28																									54	0.53	0.28
	55	0.54	0.30																									55	0.44	0.19
	56	0.63	0.40																									56	0.45	0.20
	57	0.69	0.47																									57	0.57	0.33
	58	0.62	0.38																									58	0.36	0.13
	59	0.60	0.37																									59	0.34	0.12
	60	0.67	0.45																											
	61	0.60	0.36																											
	62	0.62	0.39																											
	63	0.61	0.37																											
	64	0.65	0.43																											
	65	0.60	0.36																											
	66	0.53	0.28																											
	67	0.67	0.45																											
	68	0.32	0.10																											
	69	0.58	0.33																											
	70	0.58	0.34																											
	71	0.63	0.39																											
	72	0.69	0.48																											
	73	0.41	0.17																											
	74	0.70	0.49																											
	75	0.64	0.41																											
	76	0.57	0.32																											
Mean	0.53			0.43			0.59			0.58			0.57			0.51			0.59			0.55			0.49			0.53		

Notes: A: Item numbers; B: Loadings; C: Squares of Loadings

Table 6. Extracted Variances (Eigenvalues) of First Two Common Factors for 10 ILPS Test Data Sets

Subject	Grade	Sample Size (J)	Test Length (n')	λ_1[1] Eigen-value	λ_1[1] Percent variance	λ_2[2] Eigen-value	λ_2[2] Percent variance	Ratio λ_1/λ_2
Biology	9	(2286)	70	20.6	(29%)	3.34	(5%)	6.17
	6	(2213)	42	8.36	(20%)	1.79	(4%)	4.67
Chemistry	9	(2271)	41	14.85	(36%)	1.66	(4%)	8.97
	6	(2391)	27	9.27	(34%)	1.24	(5%)	7.51
Natural Science	9	(2243)	33	10.51	(32%)	1.7	(5%)	6.18
	6	(2390)	28	7.3	(26%)	1.49	(5%)	4.91
Physics	12	(1787)	23	6.18	(27%)	1.27	(6%)	4.89
	9	(2302)	29	10.61	(37%)	2.41	(8%)	4.41
Earth Science	9	(2327)	53	15.85	(30%)	3.29	(6%)	4.82
Science Process Skills	9	(9171)	29	9.95	(34%)	1.68	(6%)	5.93

[1] First Factor Extracted Variance

[2] Second Factor Extracted Variance

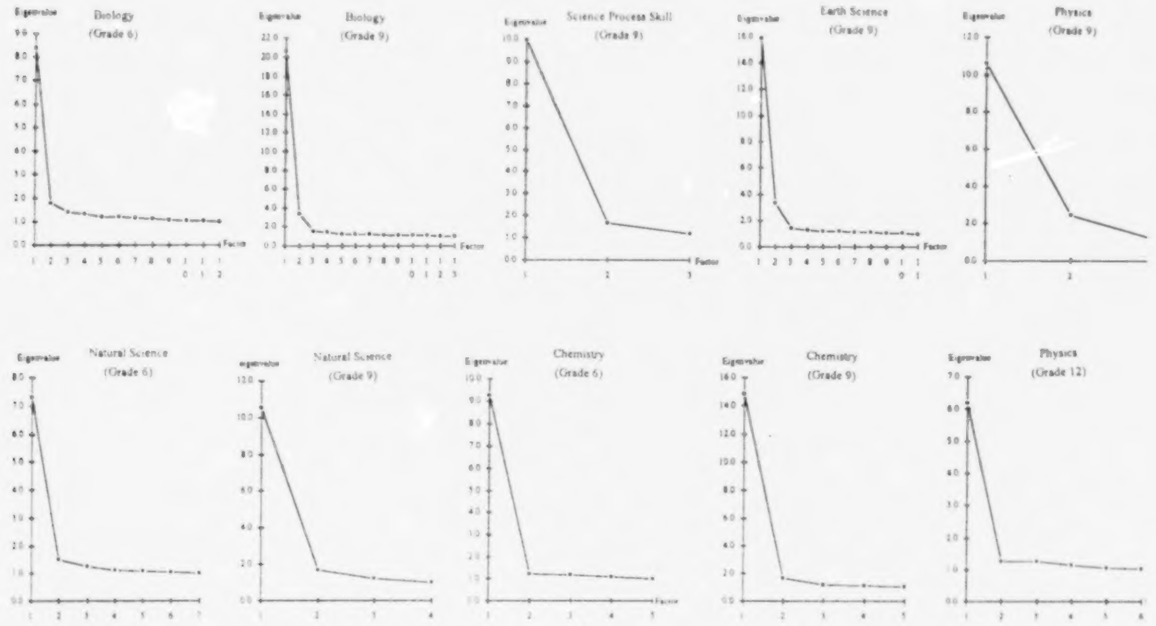


Fig. 2. Largest eigenvalues (<1.00) in order of size for the tetrachoric correlation matrices of 10 ILPS test data sets.

2. Principal Component Analysis for Homogeneity and Unidimensionality

Each of the 17 ILPS tests of length n listed in Columns 6, 11 and 16 of Table 2 was subjected to a principal component analysis on the corresponding n by n matrix of $\mathbf{R}_{tet}$. Seven ILPS tests showing non-negative definite $\mathbf{R}_{tet}$ results were suspended for further analysis. Table 5 summarizes the first common-factor loadings for items in the 10 remaining ILPS tests.

As shown in Table 5, according to a +0.30 criterion for first common-factor loading, the number of items deleted from the remaining 10 tests varied with subject and grade; the number of items deleted ranged from 2 to 14. The lengths of these 10 ILPS tests were thus reduced to 70, 42, 41, 27, 29, 23, 29, 33, 28, and 53 items, with their loading means for n' items recorded at 0.53, 0.43, 0.59, 0.58, 0.57, 0.51, 0.59, 0.55, 0.49, and 0.53, respectively. A high mean value (from

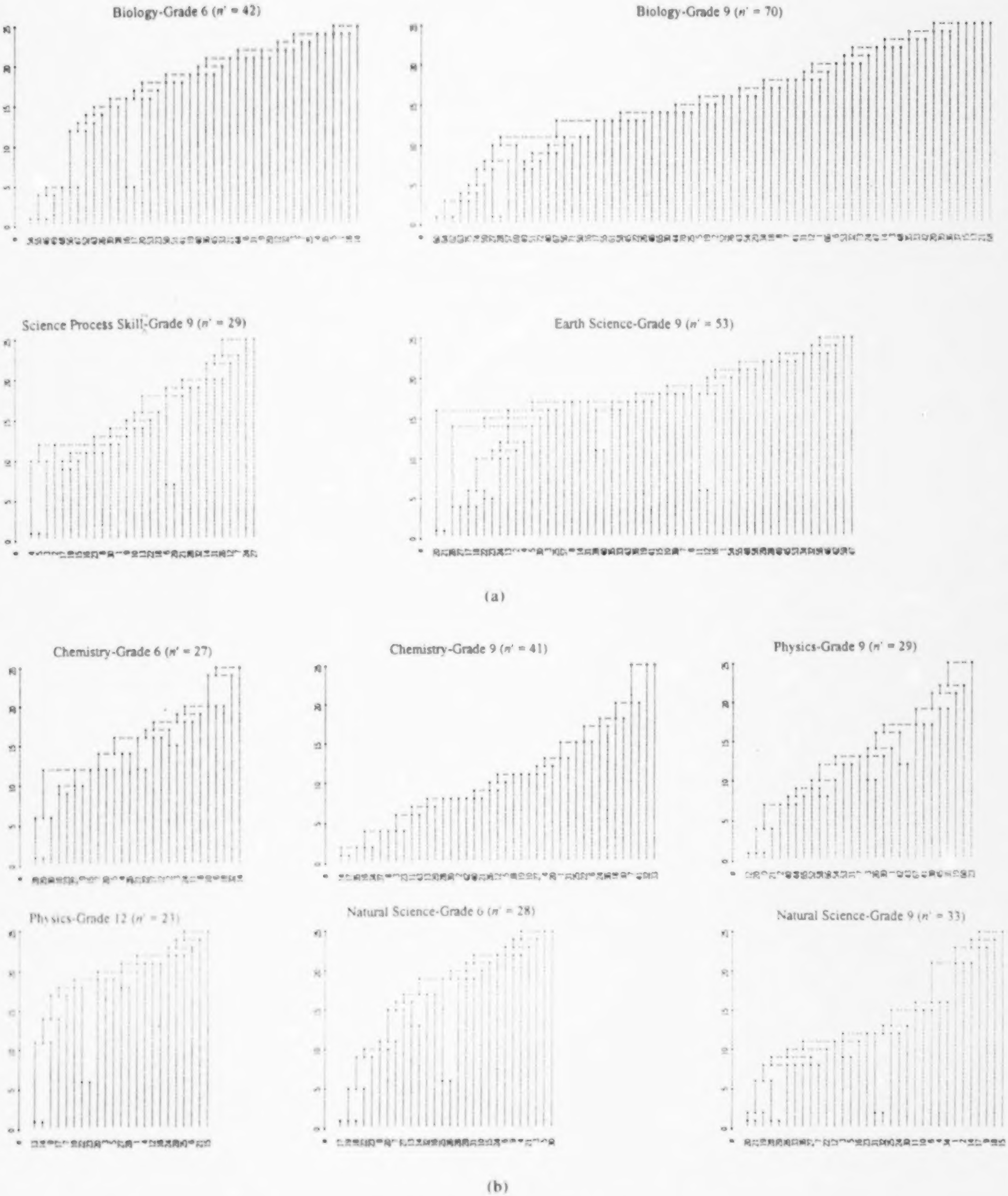


Fig. 3. (a) Dendrograms associated with biology, SPS, and earth science ILPS test items. (b) Dendrograms associated with chemistry, natural science, and physics ILPS test items.

0.43 to 0.59) indicates item homogeneity within a test item set.

Using Kaiser's criterion for the tetrachoric correlation matrices of 10 n'-item ILPS tests, Fig. 2 is a presentation of eigenvalue scree plots against the optimum number of extracted factors. Figure 3 shows that the number of factors with $\lambda \geq 1.00$ falls within a range of 3-14 across the 10 data sets. It was found that λ_2 was significantly larger than λ_3 in both data sets for grade 9 biology and earth science.

Table 6 presents: (1) the eigenvalues of the first two common factors λ_1 and λ_2, (2) the associated percentage variances, and (3) the ratios of λ_1 to λ_2. The table shows that the percentage variance of the first factor ranged from 20% to 37%, with a λ_1 to λ_2 ratio ranging from 4.41 to 8.97 across the 10 data sets. However, we found that $\lambda_2 \geq 2.00$ for the grade 9 biology, earth science, and physics data sets. Together, these results indicate: (1) the 10 ILPS test item sets with $a_{i1}F_1 \geq 0.30$ met the unidimensionality criterion set by Reckase (1979) since the percentage variances of the first factor were all above 20%; (2) when analyzed in terms of Lord's rule (Lord, 1980), the grade 9 biology, physics, and earth science test item sets could not be considered unidimensional because the second eigenvalue was much larger than any other.

3. Homogeneous Structure via Clustering Method

Figure 3(a) and (b) consist of the dendrograms produced following the application of the single linkage method to the 10 ILPS data sets; the horizontal lines denote joined items and the vertical lines denote the distance at which the items are joined. It should be noted that the original scale values (coefficients) found in Lin (1995) have been rescaled to fall within the range of 1 to 25 under the SPSS Cluster procedure.

The dendrograms in Fig. 3(a) and (b) are quite similar in shape to that presented as Panel B of Fig. 1. In addition, we failed to find any large change in values in terms of distance at any combined item stage. The ladder-like shape and small distance values among dendrogram stages suggest a lack of group structure to the data; this holds true for each of the 10 ILPS data sets. These results indicate that the ILPS test item sets which correspond to subject/grade areas are homogeneous.

We examined the dendrograms to find the core set of items having the greatest similarity. The 10 ILPS test sets corresponding to their respective dendrograms in Fig. 3(a) and (b) are (54, 55, 46, 49), (60, 64, 62, 63), (4, 5), (20, 21, 26, 27), (28, 29), (14, 17, 35, 16, 34, 37), (12, 20, 9, 21), (13, 14), (17, 19, 18, 22), and (20, 21, 19). When analyzing item stems, we found that the items within the parentheses measured the same major and minor concepts corresponding to the subject content areas previously described. On the other hand, respective sets of dissimilar items relative to those in the core sets were identified as (5, 1, 18, 14), (37, 15, 13, 21, 68), (24, 27), (59, 47), (32, 14), (7*, 41*, 32, 33), (19, 60, 23), (21*, 15), (5, 30), and (18, 15). With the exception of the three items marked with an asterisk, we found that the $a_{i1}F_1$ values for these items were all less than 0.40 (Table 5).

4. Stout's Unidimensionality Test

Table 7(a) and (b) present a summary of the results for the 10 test data sets, including score variance estimate values ($\hat{\sigma}_k^2$), unidimensional variance estimates ($\hat{\sigma}_{U,k}^2$), the normalizing constant (S_k) for each of K groups, and T_L, T_B and T values for each subject area; all values were obtained as the result of procedures described in the methodology section of this paper. The M value for item set assessment of the grade 9 subtests for biology and earth science was 7, while for all other test sets M=5. This difference was meant to compensate for the variance in test length (n') according to subject area and grade level. Readers interested in examining detailed results with respect to the $\hat{\delta}_{4,k}$, $\hat{\sigma}_k^4$, and $\hat{\mu}_{4,k}$ values involved in obtaining S_k will find them in Lin (1995).

As Table 7(a) and (b) show, the calculated values of T associated with the grade 9 biology and physics tests were 2.45 and 2.19 respectively – both larger than $Z_{0.05}$=1.65. The calculated T values associated with the other eight tests were all less than 1.65. Thus, two of the 10 data sets reject H_0: d=1 at a 0.05 level of significance, implying that the two tests contain items which load heavily on at least two dominant dimensions.

Deleting items having an $a_{i1}F_1$<0.40 from the grade 9 biology and physics tests resulted in the respective removal of 10 and 4 items. Results of an identical computing procedure for analyzing the two test data sets with n'' are presented in Table 7(c); the biology T value was measured at 1.26 while the physics T value was 0.49. Since both of the new T values were less than 1.65, the biology (60 items) and physics (25 items) test data both met the assumption of essential unidimensionality.

VI. Conclusions and Suggestions

We found that the four grade 9 biology subtests matched the Quasi-Simplex model due to their having a hierarchical order of complexity of T_1 (knowledge) < T_2 (understanding) < T_3 (application) < T_4 (integra-

Table 7(a). Stout's Unidimensionality Test for Biology, Chemistry and Earth Science ILPS Items

	Biology-9 (n'=70)			Biology-6 (n'=42)			Chemistry-9 (n'=41)			Chemistry-6 (n'=27)			Earth Science-9 (n'=53)		
	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k
k=1	0.07915	0.03374	0.01670	0.04303	0.03942	0.01356	0.05545	0.03260	0.01175	0.06250	0.04352	0.01277	0.11846	0.03511	0.01439
2	0.07453	0.03435	0.01425	0.04305	0.03723	0.01170	0.05597	0.03487	0.01245	0.05164	0.04077	0.00927	0.05043	0.03457	0.01175
3	0.09337	0.03472	0.01342	0.02182	0.04284	0.00922	0.03999	0.03360	0.01034	0.04665	0.03946	0.01000	0.08333	0.03318	0.01082
4	0.09601	0.03345	0.01327	0.05581	0.04155	0.01400	0.04157	0.03405	0.00728	0.04783	0.03946	0.00980	0.07307	0.02985	0.01364
5	0.07384	0.03269	0.01170	0.03496	0.03929	0.00735	0.05103	0.03314	0.00843	0.04408	0.03514	0.00849	0.09467	0.03096	0.01378
6	0.07399	0.03087	0.01480	0.04130	0.03656	0.00812	0.04928	0.03518	0.00775	0.04267	0.03294	0.00768	0.08009	0.02969	0.01371
7	0.07799	0.02849	0.01345	0.03862	0.03747	0.00837	0.04639	0.03113	0.00742	0.04403	0.03221	0.00735	0.05875	0.02318	0.01425
8	0.06316	0.02602	0.01200	0.04965	0.04229	0.00894	0.03951	0.03094	0.00693	0.03324	0.02656	0.00671	0.03880	0.02188	0.00819
9	0.05026	0.02729	0.01162	0.03711	0.04023	0.00678	0.04168	0.02927	0.00755	0.03833	0.02731	0.00762	0.03727	0.01693	0.01418
10	0.04973	0.02723	0.01311	0.04360	0.04224	0.00755	0.03986	0.02745	0.00883	0.03207	0.02344	0.00648	0.01757	0.01286	0.00529
11	0.03676	0.02114	0.01253	0.03714	0.04210	0.00616	0.04222	0.02827	0.00837	0.02434	0.01969	0.00592	0.02857	0.01599	0.00872
12	0.04954	0.02018	0.01905	0.04223	0.04227	0.00678	0.02466	0.02175	0.00548	0.02671	0.02036	0.00616	0.01206	0.00986	0.00520
13	0.05192	0.02091	0.01738	0.04968	0.04105	0.00686	0.02428	0.02328	0.00714	0.01796	0.01636	0.00346	0.01322	0.00937	0.00520
14	0.03782	0.01848	0.00894	0.04213	0.03841	0.00721	0.02063	0.02045	0.00490	0.01473	0.01352	0.00265	0.01239	0.00979	0.00539
15	0.03188	0.01739	0.01208	0.04366	0.04054	0.00678	0.02318	0.01872	0.00883	0.01147	0.01155	0.00141	0.00830	0.00649	0.00346
16	0.02656	0.01373	0.01015	0.05053	0.03886	0.00800	0.02028	0.01578	0.00837	0.01429	0.01374	0.00265	0.00470	0.00435	0.00245
17	0.02031	0.01359	0.00837	0.04294	0.03696	0.00877	0.01565	0.01724	0.00480				0.00921	0.00701	0.00412
18	0.02395	0.01455	0.00906	0.04257	0.04235	0.00781	0.01369	0.01124	0.00632				0.00307	0.00344	0.00141
19	0.03456	0.01503	0.01612	0.03917	0.03597	0.00849	0.01612	0.01277	0.00700				0.00517	0.00397	0.00300
20	0.01985	0.00829	0.01378	0.04479	0.03302	0.01020	0.01045	0.00852	0.00592				0.00621	0.00637	0.00265
21	0.01779	0.00832	0.01140				0.00864	0.00990	0.00332				0.00361	0.00423	0.00173
22	0.01710	0.01179	0.00656				0.00725	0.00690	0.00447				0.00315	0.00352	0.00200
23	0.00633	0.00763	0.00316				0.00674	0.00969	0.00245				0.00241	0.00260	0.00173
24	0.03619	0.01306	0.01386				0.00885	0.00955	0.00374				0.00497	0.00472	0.00283
25	0.00387	0.00469	0.00224				0.00622	0.00635	0.00332				0.00237	0.00253	0.00173
26	0.00794	0.00828	0.00374				0.00563	0.00484	0.00374				0.00491	0.00345	0.00316
27	0.00502	0.00452	0.00332				0.00649	0.00671	0.00346				0.00273	0.00301	0.00200
28	0.00378	0.00442	0.00224				0.00275	0.00269	0.00200				0.00595	0.00298	0.00529
29	0.01106	0.00830	0.00480				0.00356	0.00393	0.00265				0.00165	0.00170	0.00173
30	0.00434	0.00324	0.00361										0.00278	0.00285	0.00200
31	0.00413	0.00508	0.00245										0.00070	0.00068	0.00141
32	0.00286	0.00307	0.00245										0.00316	0.00212	0.00300
33	0.00453	0.00554	0.00200										0.00097	0.00093	0.00173
34	0.00435	0.00370	0.00316												
35	0.00518	0.00451	0.00374												
36	0.00123	0.00124	0.00173												
37	0.00456	0.00314	0.00424												
38	0.00073	0.00070	0.00141												
39	0.00073	0.00070	0.00141												
40	0.00120	0.00116	0.00141												
41	0.00093	0.00089	0.00173												
T_L	**7.44**			**1.19**			**3.37**			**3.71**			**6.10**		
k=1	0.04925	0.03163	0.01005	0.04397	0.03510	0.01010	0.03489	0.03099	0.00883	0.07957	0.04408	0.01526	0.05220	0.03364	0.00900
2	0.04345	0.03047	0.00954	0.03830	0.03738	0.00877	0.03358	0.03492	0.01015	0.04393	0.04302	0.00755	0.03007	0.03204	0.00529
3	0.04356	0.03376	0.00787	0.03016	0.03885	0.00927	0.04165	0.03564	0.00640	0.05361	0.04270	0.00964	0.04918	0.03345	0.00721
4	0.04945	0.03456	0.00894	0.03902	0.03484	0.00671	0.04548	0.03994	0.00735	0.04830	0.03885	0.00949	0.04762	0.03301	0.00648
5	0.04267	0.03381	0.00781	0.03512	0.03571	0.00707	0.04076	0.03858	0.00583	0.04506	0.03448	0.00812	0.05215	0.03088	0.00768
6	0.05680	0.03407	0.00686	0.04065	0.03673	0.00671	0.05395	0.04110	0.00632	0.04450	0.03150	0.00849	0.04043	0.03076	0.00583
7	0.04225	0.03536	0.00671	0.04514	0.03792	0.00806	0.05090	0.04001	0.00592	0.03714	0.02772	0.00624	0.05169	0.03021	0.00775
8	0.05365	0.03560	0.00949	0.03895	0.03962	0.00592	0.04984	0.03986	0.00700	0.02173	0.02147	0.00480	0.05551	0.02954	0.00906
9	0.05022	0.03492	0.00794	0.04448	0.03861	0.00640	0.06818	0.03962	0.00964	0.01428	0.01432	0.00387	0.02805	0.02375	0.00548
10	0.04801	0.03348	0.00872	0.05172	0.03989	0.00686	0.05192	0.03801	0.00831	0.02218	0.01738	0.00510	0.03121	0.02366	0.00548
11	0.04368	0.03480	0.00616	0.04461	0.03921	0.00671	0.05517	0.03832	0.01005	0.01699	0.01244	0.00469	0.02546	0.02466	0.00671
12	0.03763	0.03135	0.00831	0.04463	0.03831	0.00693	0.04185	0.03487	0.00889	0.00943	0.00954	0.00245	0.02338	0.02115	0.00469
13	0.02120	0.03017	0.00400	0.04363	0.04058	0.00735	0.04393	0.03202	0.00854	0.00445	0.00488	0.00173	0.01460	0.01465	0.00316
14	0.02993	0.03104	0.00707	0.05064	0.03722	0.00906	0.04949	0.03346	0.01000	0.00554	0.00441	0.00300	0.01514	0.01708	0.00361
15	0.02600	0.02660	0.00632	0.03116	0.03680	0.00539	0.03336	0.02446	0.00742				0.01660	0.01356	0.00583
16	0.04704	0.02659	0.01625	0.03673	0.03434	0.00800	0.02519	0.02078	0.00557				0.01139	0.01168	0.00346
17	0.03272	0.02479	0.00995	0.03636	0.03653	0.01153	0.02221	0.02096	0.00624				0.01443	0.01290	0.00775
18	0.03111	0.02479	0.00800				0.01445	0.01971	0.00469				0.01133	0.01110	0.00412
19	0.02653	0.02278	0.00671				0.01688	0.01410	0.00539				0.01142	0.00911	0.00469
20	0.01537	0.02114	0.00458				0.01223	0.01107	0.00548				0.00883	0.00686	0.00346
21	0.03135	0.02048	0.00686				0.00581	0.00735	0.00245				0.00836	0.00532	0.00539
22	0.01859	0.01641	0.00583				0.00861	0.00891	0.00346				0.00669	0.00665	0.00316
23	0.01810	0.01479	0.00583				0.00470	0.00398	0.00316				0.00603	0.00485	0.00332
24	0.01455	0.01472	0.00480				0.00281	0.00285	0.00224				0.00602	0.00477	0.00346
25	0.01239	0.01132	0.00424				0.00328	0.00346	0.00224				0.00116	0.00113	0.00141
26	0.01587	0.01272	0.00500										0.00282	0.00136	0.00346
27	0.01122	0.00700	0.00721										0.00064	0.00062	0.00100
28	0.01242	0.01058	0.00447										0.00366	0.00426	0.00245
29	0.01017	0.00845	0.00480												
30	0.01380	0.01004	0.00806												
31	0.00752	0.00835	0.00346												
32	0.00680	0.00745	0.00387												
33	0.00777	0.00438	0.00648												
34	0.00572	0.00570	0.00332												
35	0.00694	0.00513	0.00436												
36	0.00237	0.00242	0.00200												
37	0.00376	0.00426	0.00265												
38	0.00680	0.00629	0.00458												
T_B	**3.98**			**1.81**			**3.79**			**2.93**			**4.10**		
T	**2.45***			**-0.44**			**-0.29**			**0.55**			**1.41**		

Notes: * Reject; H_0: d=1 if $T>Z_{0.05}(=1.65)$, $T=(T_L-T_B)/\sqrt{2}$

Table 7(b). Stout's Unidimensionality Test for Natural Science, SPS, and Physics ILPS Items

	Natural Science-9 ($n'=33$)			Natural Science-6 ($n'=28$)			Science Process Skill-9 ($n'=29$)			Physics-12 ($n'=23$)			Physics-9 ($n'=29$)		
	$\hat\sigma^2_k$	$\hat\sigma^2_{U,k}$	S_k	$\hat\sigma^2_k$	$\hat\sigma^2_{U,k}$	S_k	$\hat\sigma^2_k$	$\hat\sigma^2_{U,k}$	S_k	$\hat\sigma^2_k$	$\hat\sigma^2_{U,k}$	S_k	$\hat\sigma^2_k$	$\hat\sigma^2_{U,k}$	S_k
$k=1$	0.04113	0.03930	0.00985	0.03502	0.03604	0.01086	0.09714	0.04696	0.01597	0.06277	0.04223	0.01631	0.06731	0.03769	0.01836
2	0.04444	0.03864	0.01109	0.02683	0.03515	0.00906	0.08567	0.04733	0.01118	0.04493	0.03477	0.01208	0.08586	0.04326	0.01349
3	0.04106	0.04103	0.00700	0.06635	0.04212	0.01746	0.06953	0.04425	0.00954	0.05129	0.03489	0.01281	0.08406	0.04650	0.01068
4	0.05102	0.03709	0.00964	0.04710	0.04327	0.00794	0.07779	0.04460	0.00748	0.04306	0.03944	0.00883	0.07223	0.04640	0.00860
5	0.04391	0.03972	0.00728	0.05240	0.04166	0.00877	0.08325	0.04211	0.00755	0.04953	0.04209	0.00762	0.07306	0.04157	0.01000
6	0.03783	0.04043	0.00608	0.04448	0.04390	0.00748	0.05624	0.03810	0.00548	0.06338	0.04250	0.00806	0.04227	0.03612	0.00686
7	0.03153	0.03811	0.00529	0.05804	0.04676	0.00819	0.04818	0.03184	0.00469	0.07016	0.04498	0.00831	0.04764	0.03515	0.00849
8	0.03129	0.03281	0.00671	0.04946	0.04573	0.00812	0.04048	0.02618	0.00539	0.05338	0.04341	0.00624	0.03889	0.03678	0.00583
9	0.04731	0.03730	0.00866	0.05960	0.04672	0.00721	0.02851	0.02203	0.00400	0.06015	0.04405	0.00735	0.04287	0.03496	0.00794
10	0.04058	0.03597	0.00806	0.05469	0.04733	0.00583	0.02368	0.01689	0.00436	0.06250	0.04461	0.00728	0.04524	0.03720	0.00872
11	0.04652	0.04405	0.00894	0.06603	0.04799	0.00648	0.01404	0.01272	0.00245	0.06427	0.04062	0.00748	0.03935	0.03866	0.00624
12	0.05485	0.03992	0.00985	0.06467	0.04868	0.00583	0.01278	0.01090	0.00300	0.04278	0.03617	0.00686	0.04076	0.03877	0.00762
13	0.03568	0.03609	0.00787	0.06735	0.04705	0.00608	0.00806	0.00719	0.00200	0.04519	0.03484	0.00927	0.05841	0.04249	0.01122
14	0.05404	0.04181	0.00949	0.07138	0.04640	0.00735	0.00712	0.00696	0.00173	0.04750	0.02986	0.01086	0.06203	0.04161	0.01149
15	0.04673	0.03901	0.01100	0.05595	0.04030	0.00755	0.00750	0.00640	0.00200	0.04302	0.02899	0.01127	0.05277	0.03991	0.01025
16	0.05526	0.04384	0.01044	0.05213	0.04017	0.00831	0.00664	0.00600	0.00141	0.03429	0.01887	0.01510	0.05583	0.04151	0.00877
17	0.06141	0.04353	0.01054	0.05020	0.04002	0.01030	0.00434	0.00396	0.00141				0.05753	0.04052	0.01109
18	0.05089	0.04109	0.00849				0.00324	0.00346	0.00100				0.06232	0.03771	0.01058
19	0.08015	0.04533	0.01281				0.00254	0.00267	0.00100				0.05127	0.03170	0.01237
20	0.06812	0.03687	0.01375				0.00278	0.00266	0.00100				0.04495	0.02748	0.01192
21	0.03570	0.02498	0.01136				0.00283	0.00257	0.00141				0.04114	0.02283	0.01091
22	0.04854	0.02647	0.01539				0.00383	0.00322	0.00265				0.02445	0.02051	0.00927
23	0.04182	0.02318	0.01761												
24	0.01328	0.01597	0.00648												
T_L	**3.73**			**5.78**			**7.43**			**6.44**			**7.37**		
$k=1$	0.04036	0.03430	0.01330	0.02507	0.03597	0.00900	0.05400	0.04705	0.00825	0.05460	0.03990	0.01970	0.05222	0.02250	0.02890
2	0.03621	0.03801	0.00728	0.05676	0.04250	0.01612	0.07386	0.04790	0.00748	0.04790	0.04029	0.00964	0.03120	0.02464	0.00787
3	0.04122	0.03759	0.00794	0.04833	0.04136	0.01127	0.06712	0.04851	0.00510	0.05471	0.04593	0.00854	0.03942	0.02610	0.00825
4	0.03813	0.04009	0.00648	0.05088	0.04338	0.00980	0.06711	0.04883	0.00436	0.05609	0.04661	0.00728	0.03944	0.03469	0.00843
5	0.03371	0.03988	0.00510	0.03902	0.04615	0.00768	0.07542	0.04805	0.00424	0.04911	0.04497	0.00632	0.05041	0.03641	0.00800
6	0.03984	0.03709	0.00700	0.05268	0.04015	0.00943	0.06090	0.04417	0.00361	0.05472	0.04525	0.00600	0.04969	0.04269	0.00632
7	0.03822	0.04051	0.00640	0.04814	0.04660	0.00640	0.05793	0.03762	0.00412	0.06163	0.04462	0.00678	0.05847	0.04605	0.00700
8	0.04212	0.04343	0.00663	0.06089	0.04897	0.00781	0.04721	0.03325	0.00424	0.05205	0.04278	0.00574	0.06338	0.04850	0.00721
9	0.04441	0.04233	0.00748	0.06104	0.04835	0.00671	0.03960	0.02916	0.00361	0.04633	0.03834	0.00539	0.05880	0.04851	0.00755
10	0.04290	0.04460	0.00693	0.06326	0.04938	0.00500	0.03322	0.02586	0.00332	0.04808	0.03914	0.00648	0.06381	0.04733	0.00854
11	0.05925	0.04527	0.00812	0.05958	0.04814	0.00510	0.01902	0.01514	0.00283	0.03757	0.02854	0.00843	0.05750	0.04295	0.00837
12	0.04554	0.04694	0.00693	0.05454	0.04541	0.00480	0.01474	0.01236	0.00245	0.02888	0.02237	0.01020	0.05695	0.04005	0.00860
13	0.05421	0.04525	0.00812	0.05406	0.04347	0.00529	0.01096	0.01002	0.00200				0.04012	0.03460	0.00843
14	0.05002	0.04033	0.00748	0.03658	0.03822	0.00548	0.00933	0.00848	0.00173				0.02519	0.02476	0.00500
15	0.05661	0.04435	0.00883	0.04015	0.03378	0.00911	0.00693	0.00671	0.00141				0.02321	0.02010	0.00583
16	0.04152	0.04256	0.00608				0.00486	0.00471	0.00141				0.01564	0.01982	0.00510
17	0.04243	0.03828	0.00787				0.00346	0.00364	0.00141				0.01201	0.01073	0.00632
18	0.03912	0.03190	0.00831				0.00259	0.00264	0.00173				0.01422	0.01142	0.00671
19	0.03118	0.02825	0.00735										0.00736	0.00818	0.00500
20	0.02367	0.01866	0.00819												
T_B	**1.47**			**3.72**			**9.41**			**4.27**			**4.27**		
T	**1.60**			**1.45**			**-1.40**			**1.54**			**2.19***		

tion). On the other hand, the four grade 6 biology subtests deviated from this hypothesized order, the hierarchical order in that case being $T_1<T_2<T_4<T_3$. In terms of difference in magnitude of complexity loading, we found that Form A of the grade 9 biology test contained items measuring at least two cognitive levels (knowing and understanding), whereas its grade 6 counterpart contained items measuring at least three (knowing, understanding, and integration/application).

The implications of these findings are as follows: (1) for the grade 6 and 9 biology ILPS tests, in both cases Form A measured more than simple factual knowledge; (2) panel experts were less capable of creating effective items for the measurement of application and integration skills than they were for items which measure knowledge and understanding; and (3) the Simplex model is a useful tool for enhancing test quality in that it offers a supplementary means of verifying which cognitive processes are measured by individual test items. However, obtaining more generalized results by means of the Simplex theory requires at least seven subtests of the same kind, with the lengths of the subtests being as equal as possible.

In this paper we proposed the use of dendrograms to investigate whether ILPS test items with first factor loadings ≥ 0.30 maintain a homogeneous structure. Results show that the dendrograms associated with all of the 10 ILPS tests presented in Fig. 4(a) and (b) revealed a lack of distinct group structure. This finding suggests that: (1) the traditional criterion of $a_{i1}F_1 \geq 0.30$ can be established during the initial stage of scale construction for the purpose of selecting a more homogeneous set of test items; and (2) dendrograms can be used as graphical representations of similarity structure among homogeneous item sets. It is also possible to further distinguish a fairly homo-

Table 7(c). Stout's Unidimensionality Test for Biology and Physics Items with a $a_{i1}F_1 \geq 0.40$

	Biology-9 (n'=60)						Physics-9 (n'=25)					
	T_L			T_B			T_L			T_B		
k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k	$\hat{\sigma}_k^2$	$\hat{\sigma}_{U,k}^2$	S_k
1	0.05699	0.03753	0.01114	0.04655	0.03292	0.01058	0.02898	0.02027	0.01145	0.01158	0.00866	0.00510
2	0.06713	0.03915	0.01285	0.04364	0.03970	0.01068	0.02907	0.02460	0.00721	0.01886	0.01498	0.00490
3	0.07526	0.03729	0.01068	0.04844	0.03903	0.01015	0.02926	0.02892	0.00510	0.02900	0.02185	0.00412
4	0.07544	0.03653	0.01729	0.06454	0.04028	0.00860	0.03189	0.03189	0.00447	0.03142	0.02550	0.00436
5	0.06781	0.03639	0.01153	0.04868	0.04006	0.00927	0.03585	0.03249	0.00469	0.04107	0.02981	0.00616
6	0.07916	0.03350	0.01367	0.04910	0.04054	0.00906	0.02573	0.02884	0.00436	0.04489	0.03175	0.00648
7	0.05665	0.03094	0.01140	0.04148	0.03951	0.00707	0.02860	0.02848	0.00458	0.04132	0.03578	0.00510
8	0.04778	0.02820	0.01005	0.05012	0.03988	0.00938	0.03070	0.02829	0.00693	0.04966	0.03715	0.00608
9	0.06666	0.03302	0.01396	0.05280	0.03662	0.00975	0.04296	0.03088	0.00825	0.04633	0.03961	0.00592
10	0.04675	0.02376	0.01581	0.05281	0.03606	0.00883	0.04694	0.03360	0.00819	0.04917	0.03853	0.00600
11	0.03500	0.02514	0.00748	0.03991	0.03744	0.00714	0.04607	0.03419	0.00671	0.04447	0.03512	0.00608
12	0.03387	0.02298	0.00849	0.03606	0.03308	0.00707	0.06337	0.03550	0.00933	0.03333	0.03142	0.0049(
13	0.02752	0.01957	0.00648	0.03966	0.03341	0.00693	0.05831	0.03697	0.00860	0.03674	0.02918	0.00529
14	0.02816	0.01871	0.01054	0.02702	0.02593	0.00748	0.06842	0.03552	0.01077	0.02969	0.02535	0.00671
15	0.02436	0.01808	0.00872	0.02928	0.02735	0.00656	0.05963	0.03526	0.00985			
16	0.03530	0.02137	0.01058	0.03072	0.02384	0.00748	0.05920	0.03044	0.00843			
17	0.01811	0.01608	0.00600	0.02642	0.02309	0.00671	0.04294	0.02393	0.00883			
18	0.00832	0.01043	0.00346	0.01886	0.01830	0.00539	0.02420	0.01766	0.00566			
19	0.01157	0.01081	0.00447	0.02730	0.01685	0.00985	0.01538	0.01274	0.00510			
20	0.00855	0.01027	0.00374	0.01280	0.01245	0.00469	0.00968	0.00901	0.00500			
21	0.00910	0.00797	0.00436	0.02239	0.01299	0.00922						
22	0.01233	0.00952	0.00510	0.01803	0.01607	0.00663						
23	0.01752	0.01489	0.00806	0.01823	0.01280	0.00742						
24	0.00955	0.01134	0.00361	0.01911	0.01524	0.00648						
25	0.01036	0.00676	0.00592	0.01379	0.01353	0.00728						
26	0.00710	0.00680	0.00447	0.00942	0.00887	0.00480						
27	0.00319	0.00340	0.00245	0.01031	0.00928	0.00510						
28	0.00527	0.00634	0.00332	0.00628	0.00826	0.00332						
29	0.00570	0.00449	0.00436	0.00810	0.00862	0.00458						
30	0.00437	0.00483	0.00300	0.00359	0.00392	0.00283						
31	0.00397	0.00191	0.00490	0.00822	0.00884	0.00424						
32	0.00342	0.00370	0.00300	0.00603	0.00775	0.00316						
33	0.00202	0.00208	0.00224	0.00530	0.00419	0.00412						
34	0.00368	0.00388	0.00265	0.00784	0.00508	0.00520						
35	0.00198	0.00198	0.00245	0.00542	0.00403	0.00458						
36	0.00075	0.00073	0.00141									
37	0.00084	0.00082	0.00141									
38	0.00173	0.00168	0.00224									
		T_L=5.09			T_B=3.30			T_L=5.60			T_B=4.9	
			T=1.26						T=0.49			

geneous item set from a fairly dissimilar one by means of examining a dendrogram's distance coefficient values.

We also proposed the use of Stout's method (Stout, 1987) for investigating the extent to which ILPS test data holds unidimensionality via a comparison of results based on the rules of thumb stated by Reckase (1979) and Lord (1980). We found that the 10 ILPS tests with items showing an $a_{i1}F_1 \geq 0.30$ satisfied Reckase's unidimensionality criterion. On the other hand, the data for the grade 9 biology, physics, and earth science tests failed to comply with Lord's criterion, with the first two also failing to meet Stout's definition of essential unidimensionality. However, the deletion of items with $a_{i1}F_1 < 0.40$ resulted in the grade 9 biology and physics tests meeting Stout's criterion.

It therefore appears that, relative to Stout's criterion, Reckase's criterion is lenient while Lord's is conservative. However, it must be pointed out that Stout's definition of unidimensionality is based on $\frac{1}{n(n-1)} \sum_{1 \leq i \neq j \leq n} |Cov(U_i, U_j|\theta)| \approx 0$, which implies that items are of essential unidimensionality if test data support H_0: d=1. On the other hand, for those who prefer the traditional definition of unidimensionality based on $g(\mathbf{u}) = \int_{-\infty}^{\infty} g(\mathbf{u}|\theta) f(\theta)\, d(\theta)$ for all $\mathbf{u}$, it may be preferable to apply Lord's rule to assess a test's unidimensionality.

Two other noteworthy suggestions are implied by our findings. The first is that the assessment of unidimensionality by means of inspecting whether test items measure the same content area (as panel experts are inclined to do) is unacceptable. For example, our natural science test data sets composed of items which measure six diverse content areas (shown in Table 1) held an assumption of unidimensionality regardless of which assessment criteria was used. Thus, from a latent-theory point of view, test unidimensionality as defined by **(5)** or **(7)** requires a statistical assessment procedure rather than one based on a panel study. The second suggestion is that the iterated deletion of test items is necessary to assure test unidimensionality; this requires that the first drafts of all tests be two to three times longer than their final versions. It then becomes important to note that Stout's procedure can only be used to analyze data when test length is a minimum of 25 items and sample size is a minimum of 750.

Finally, we described a procedure for showing how the four statistical methods discussed in this paper can function in the development of ILPS tests which comply with the criteria set by the commissioned project (Shin & Cheng, 1994). According to this procedure: (1) a rigid panel study is required for evaluating and identifying the cognitive process to be measured by specific items. (2) During the pretest stage, Simplex models can be used to examine whether a set of subtests or a set of individual items conforms to a quasi-simplex hypothesis. (3) The $a_{i1}F_1 \geq 0.30$ component analysis criterion may be used for finding and eliminating heterogeneous items, after which the remaining item data are subject to a cluster analysis which produces a dendrogram for ascertaining homogeneity. (4) Stout's procedure may be used for testing the unidimensionality of test data; if the data reject the null hypothesis that H_0: $d=1$, then it is possible to further delete items with $a_{i1}F_1 < 0.40$. (5) If test data survive Stout's significance test for unidimensionality, it is possible to use IRT models for calibrating ILPS test items.

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Structure & Dimensionality of ILPS Test Item

檢視 ILPS 測驗試題之結構及維度

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摘　要

本文針對科學學習進展指標(ILPS)編製過程的雙重考量，而提出四種相關的統計方法，分別檢視ILPS測驗試題認知複雜度結構、試題同質性、群簇性及單維性。以Quasi-Simplex model檢視生物ILPS測驗之四個分測驗(subtests)的複雜度階層，研究結果顯示國中生物甲卷測驗試題複雜度具有知曉<了解<應用<統整之階層順序，而國小甲卷則具有知曉<了解<統整<應用之階層順序。雖然研究結果亦顯示應用及統整分測驗複雜係數之差距不顯著，但整體試卷可視爲不只測試記憶的反芻。此外，研究結果亦顯示：學科專家判斷試題的知曉及了解認知層次的客觀性高於判斷試題之應用及統整層。

10份ILPS測驗之各份試題依主成份因素分析之傳統參照標準($a_{i1}F_1 \geq 0.30$)所保留的試題，經群簇分析所得的樹狀圖無明顯的群簇出現，顯示試題滿足同質性的特徵。在此參照標準下，(1)10份ILPS測驗皆滿足Reckase之單維指標，因各份試題之第一主成份因素特徵值皆佔總變異量之20%以上；(2)但其中有三份測驗較不符合Lord之單維指標，因第二主成份因素之特徵值較顯著性地大於其後餘因素之特徵值；(3)依據Stout的單維定義及考驗，除國中生物及物理ILPS測驗以外，其餘8份測驗試題皆滿足單維假設；(4)此二份ILPS測驗，以$a_{i1}F_1 \geq 0.40$所保留的試題，則亦滿足單維假設。

依據分析結果，本研究建議編製及分析ILPS之程序及配合要點，以期符合指標內涵及合理應用IRT模式

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(Invited Review Paper)

Linking STS Teacher Development and Certification

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(Received March 27, 1997; Accepted May 3, 1997)

Abstract

This paper describes a performance-based STS teacher education system developed by the author. The system consists of the following components linking teacher development and certification: (1) a curriculum framework for STS teacher development; (2) a constructivist model of STS teacher development with formative evaluation; (3) a set of performance criteria of STS teachers; and (4) a performance-based certification method for STS teachers. These components were designed and developed since 1993 based on a series of action research studies conducted in real teaching and learning contexts. The curriculum framework provides a way of thinking for teacher educators and/or teachers to identify, select, organize, and sequence STS activities for professional development. Novices need guidance; and professional development is more efficient using anchored, scaffolded, and independent practices with formative evaluation. A set of performance criteria for STS teachers was identified from a set of interpretive research studies; data were collected from classroom observations, in-depth interviews, teachers' journals, and portfolios. The STS teacher certification method is based on evidence obtained from portfolios presented by teachers; the method is relevant to a set of stipulated criteria. These data were collected during one or two years of professional development programs and coupled with actual teaching observations and interviews by evaluators. Performance-based STS teacher education links teacher development and certification. The system can improve instruction for STS learning, identify qualified teachers, and stimulate domestic educational reform.

Key Words: certification, performance-based evaluation, science teachers, STS, teacher development

I. Introduction

In the Republic of China, the standardized curricula and the joint entrance examinations have had fixed learning and teaching styles for many years. The traditional science teaching methods met with many problems (Wang, 1995a). Learners could transfer only little of their learning to new real life situations (cf. Wheatley, 1991). New forms of education are needed. Experiencing in world situation is the fundamental way for educating citizens who will take responsibility in promoting social welfare and handling life-related problems. STS education is to develop science literate citizens with capabilities of creativity, higher order thinking, critical thinking, value analyses, ethical and moral consideration, decision making, and problem solving. STS literacy cannot be cultivated by teaching methods of the cook-book type. Learners must learn not only the elements needed, but also make combined use of these learning elements to solve newly encountered real life problems (Rubba, 1991). Teachers are the key to success in science education reform. In pursuing STS education, teachers must internalize STS beliefs and clearly understand the teaching goals. They must also have STS professional capabilities and be willing to develop their own STS modules for their students without relying on textbooks (Yager, 1990, 1992; Wang, 1995a).

Recent educational reforms in the R.O.C. have decentralized authority of teacher education and licensure, so the goals of teacher education can be accomplished only through unified approach. Learning standards for students must be matched with standards for teachers. Licensing requirements must assure that all students are taught effectively. A widely accepted set of standards for performance of teaching professionals is needed to ensure consistency and compatibility.

How should we develop teachers' professional capabilities? How should we monitor and report progress? How should data be collected and recorded (e.g., checklists, narratives, video recorded, or portfolios)? How should we evaluate teacher qualification? How should we handle bias? How should we help the evaluatee improve after we have identified a profile of strengths and weaknesses?

To promote STS education requires a large number of STS teachers. In April 1994 the author visited the University of Iowa to observe a Chauttauqua STS Workshop. In August 1994, Dr. Robert E. Yager was invited for a five-day workshop at National Taiwan Normal University. A collaborative STS research project (August 1995 - July 1998) was then promoted by the NSC Science Education Division. Systematic, well planned, and integrated collaborative research endeavors are needed to achieve the goal within a reasonably short period of time, because many components of STS teacher education are interrelated. The collaborative project has included 10 individual research studies for Grades 1-12 teacher preparation. Activities were all sponsored by the NSC Science Education Division. Each investigator has (1) created (i) a typical STS module for a specific issue, subject matter, and type of learners and locality; (ii) relevant STS data-banks (including STS units, assessment tools, STS resource materials, media, etc.); (2) evaluated the module's effectiveness in achieving STS learning goals; (3) examined (i) the teaching and learning process; (ii) the teacher abilities required; (iii) efficiency in promoting professional abilities; (4) assessed learning achievement; (5) designed a curriculum framework for STS teacher preparation; and (6) considered problems encountered during the research. All the members of the project have met regularly to exchange experiences and solve problems encountered during the studies.

II. A Performance-based STS Teacher Education System

STS education is different from the usual type of curriculum, instruction, and evaluation found in traditional science classrooms. It is different from what most teachers were prepared to deliver. Beliefs and the values of science teachers have been constructed out of personal school experiences, science education they received, and their own science teaching experiences. Before teachers can develop appropriate STS concepts (see Appendix) and put them into practice, the teachers need opportunities to (1) examine their beliefs and values about responsible citizen action on STS issues, (2) find a place of STS in school science education, (3) confront inconsistencies in their beliefs and values about STS action as a science education goal, and (4) construct more appropriate beliefs, values, and corresponding science teaching practices (Rubba, 1991).

The author proposes that STS teachers be viewed as a category in terms of a prototype structured by the similarity of characteristics of STS teachers to one another (cf. Sternberg & Horvath, 1995). A performance-based STS teacher education system was designed and developed by the author to provide opportunities and evidence of professional growth and certification for preservice/beginning teachers from real teaching situations. This system consists of four components: (1) a curriculum framework for STS teacher development; (2) a constructivist model of STS teacher development with formative evaluation; (3) a set of performance criteria of STS teachers; and (4) a performance-based certification method for STS teachers. The relationships among the four components are shown in Fig. 1. Curricula frameworks and the criteria for a prototype STS teacher are guidelines for teacher development. In turn, portfolios developed during teacher preparation are used as a part of the evidence for certification.

The four components were developed based on a series of action research studies in authentic contexts (Fig. 1). A primal curricula framework needed for professional development was designed based on the relevant literature. Using the primal framework, STS modules "Cooking Oil" (Wang & Yu, 1994) and "Detergent" (Wang & Tsai, 1994a) were developed by the preservice teachers (Wang, 1993). The primal framework underwent continual revision and improvement during the development of these two modules, to become the prototype framework. "Ozone Depletion" (Wang & Liu, 1995), "Greenhouse Effect" (Wang, 1994a), "Acid Rain" (Wang & Hsieh, 1997a, 1997b), and other STS modules were developed using the prototype framework.

The prototype framework provides a way of thinking for educators to establish the goals for teacher preparation, identify curriculum contents and representative modules (on global, regional, and daily life issues), and cultivate STS teachers' capabilities. A set of performance criteria for STS teachers was identified from group of exemplary STS teachers through a series of interpretive research studies including studies previously identified. Data were collected from classroom observations, in-depth interviews, teachers' journals, and portfolios. Twelve types

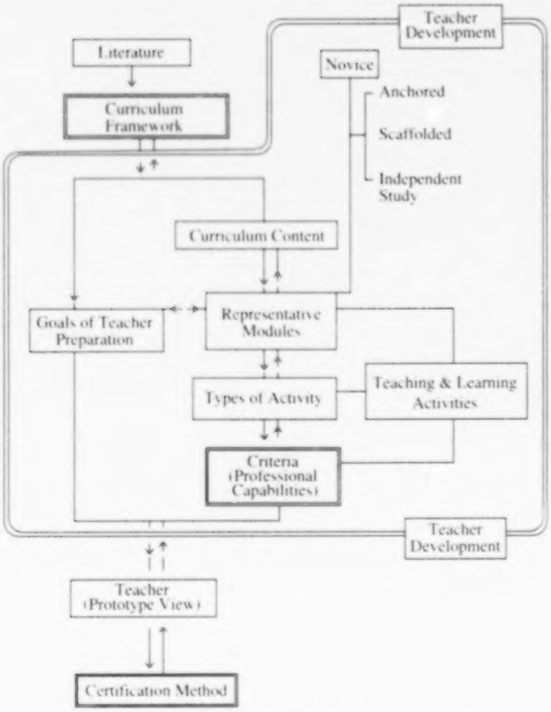
Literature
Curriculum Framework
Teacher Development
Novice
Anchored
Scaffolded
Independent Study
Curriculum Content
Goals of Teacher Preparation
Representative Modules
Types of Activity
Teaching & Learning Activities
Criteria (Professional Capabilities)
Teacher Development
Teacher (Prototype View)
Certification Method

Fig. 1. Development of an STS teacher education system.

A dynamic framework (Fig. 2) was synthesized from the literature and developed through a series of action research studies. The framework provides a way of thinking for teacher educators and/or teachers to identify, select, organize, and sequence STS activities for professional development. The framework consists of the following components (Appendix) (Wang, 1994b, 1996a): (1) a rationale for STS learning; (2) learning goals and elements (Fig. 3); (3) major STS concepts and assumptions; (4) a procedure for developing learning units and modules (Fig. 4); (5) learning phases; (6) a procedure for professional development (Fig. 5); (7) types of STS activities; (8) learning activities; (9) instructional strategies; (10) assessment strategies; (11) performance criteria for STS teachers; and (12) representative modules and guidelines for selecting STS activities.

of STS activities (e.g., role playing, exploratory experiment; see Appendix) sufficient to cover teaching and learning activities for STS teacher development were identified (Wang, 1996). It was observed that novices need guidance; professional development for them was more efficient using anchored, scaffolded, and independent practices guided by formative evaluation using the criteria. The STS teacher certification method is based on evidence obtained from portfolios developed by teachers during one or two years of professional development (Wang & Hsieh, 1997a, 1997b), coupled with an actual teaching observation and interviews by evaluators (Stanley & Popham, 1988).

III. A Curriculum Framework for STS Teacher Development

Because STS education is learner-centered and issue-oriented learning linked to the real life outside the classroom, STS teachers need a variety of "teach, learn, and assess" strategies to deal with many different problems, contexts, and contents related to many branches of science and technology.

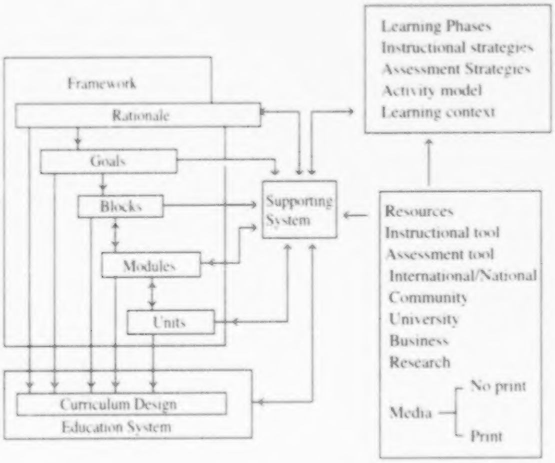
Framework
Rationale
Goals
Blocks
Modules
Units
Supporting System
Curriculum Design
Education System
Learning Phases
Instructional strategies
Assessment Strategies
Activity model
Learning context
Resources
Instructional tool
Assessment tool
International/National
Community
University
Business
Research
Media
No print
Print

Fig. 2. A curriculum framework for STS teacher development.

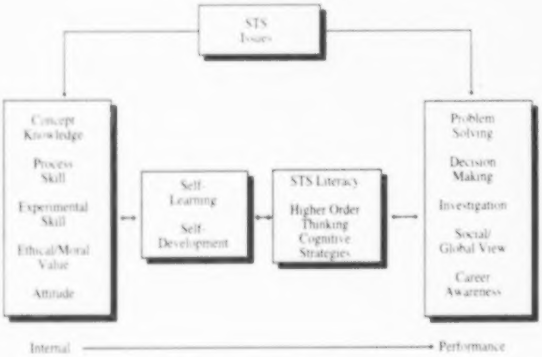
STS Issues
Concept Knowledge
Process Skill
Experimental Skill
Ethical/Moral Value
Attitude
Self-Learning
Self-Development
STS Literacy
Higher Order Thinking Cognitive Strategies
Problem Solving
Decision Making
Investigation
Social/ Global View
Career Awareness
Internal
Performance

Fig. 3. Learning goals and elements.

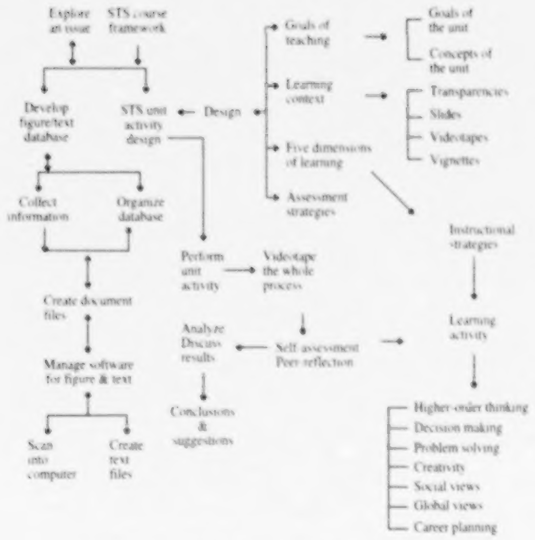
Explore an issue
STS course framework
Develop figure/text database
STS unit activity design
Design
Goals of teaching
Learning context
Five dimensions of learning
Assessment strategies
Goals of the unit
Concepts of the unit
Transparencies
Slides
Videotapes
Vignettes
Collect information
Organize database
Instructional strategies
Perform unit activity
Videotape the whole process
Create document files
Analyze Discuss results
Self assessment Peer reflection
Learning activity
Manage software for figure & text
Conclusions & suggestions
Higher-order thinking
Decision making
Problem solving
Creativity
Social views
Global views
Career planning
Scan into computer
Create text files

Fig. 4. Procedure for developing STS unit activities.

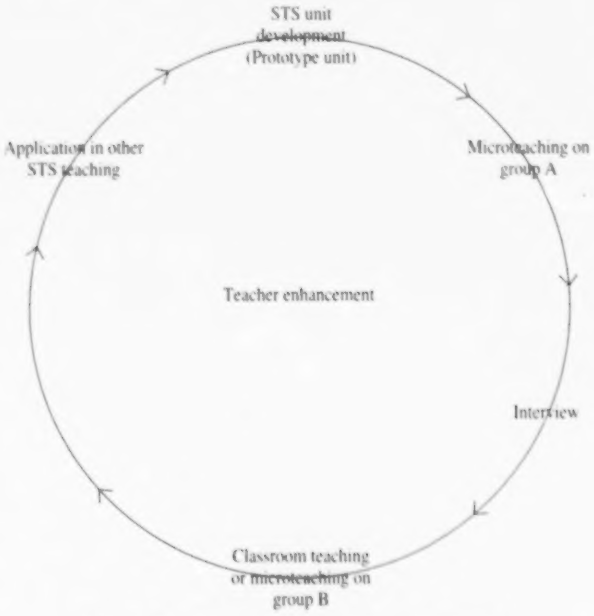
STS unit ~~development~~ (Prototype unit)
Microteaching on group A
Interview
Classroom teaching or ~~microteaching~~ on group B
Application in other STS teaching
Teacher enhancement

Fig. 5. Procedures for professional development.

IV. A Constructivist Model of STS Teacher Development

The model was developed based on the following rationale (Wang, 1994b): (1) Teachers must have personal involvement with STS-related social issues and problems, because people do not solve problems by the logical application of decontextualized knowledge (Schuman, 1987). If solving a problem is determined by the specific situation in which the problem presents itself, then learning how to solve the problem also has to be developed in that situation. (2) The curriculum development model using RDDA (research, development, diffusion, and adoption) model has been found to be ineffective. The division of labor between goal setters and goal implementers, and between practioners and valuators should be eradicated (Yager, 1992). (3) The teacher has to learn as a learner; learn how to learn, how to teach, and how to construct knowledge (Cunningham, 1991). Instruction must move the novice toward independence for professional practice. This can be accomplished through anchored, scaffolded (Rosenshine & Meister, 1992) instruction or the regulation of task difficulty, gradually reducing the instructors support as the learner's proficiency increases (cf. Bruner, 1978; Pearson and Fielding, 1991).

From our action research, we have observed that STS teacher development should go through anchored, scaffolded, and independent practices (Wang, 1995b). It is advisable that preservice teachers (hereafter called teachers) in their senior year start to participate in the first and the second stages of the program; independent work should be done during the internship period. Teachers can join in the program individually as a small group or as a class.

The following description is for an STS class.

(1) Stage 1. STS learning under anchored instruction

The teacher experiences the STS approach for teaching and learning in the context of information rich video-based anchors that serve as "macro-contexts" for STS activities; these anchors en- courage students and teachers to pose and solve complex, realistic problems. Two modules, "Cooking Oil" and "Detergent," focused on health, pollution, values, science, and technology issues (Wang, 1994a, 1994c; Wang & Yu, 1994; Wang & Tsai, 1994a). The best way for a teacher to understand the STS way of learning and teaching is to actively be engaged in the activities that the video-based anchors present. The activities using problem-centered cooperative learning consist of (i) individual work, (ii) group discussion, (iii) role playing and debating, (iv) brain storming, (v) oral and written reports, and (vi) student-made games. During the activities mapping is used as a thinking tool for cultivating students' ability to plan and solve problems through a constructivist learning model. Meaningful learning occurs when an individual (1) recognizes a connection between the new learning elements and the elements previously learned, and (2) modifies his or her individual cognitive framework to accommodate the new ones. Students act as active builders, rather than passive recipients, of information. Maps are constructed as mind maps for the teacher and the students to improve instruction and learning in real contexts. Teachers are assessed for their learning outcomes and asked to provide feedback and self-evaluation on teaching and learning strategies in the STS activities (Wang, 1993; Wang & Tsai, 1994a; Wang & Hsieh, 1997a, 1997b).

(2) Stage 2. STS unit development under scaffolded instruction

The STS learning framework is used by the researcher to scaffold and help novice science teachers working in small groups to develop STS modules (Wang & Tsai, 1994b; Wang, 1995b). (i) The class selects an STS problem of their choice after brainstorming, and divides themselves into small groups with a sub-problem for each. (ii) Each small group designs and works on an STS unit. (iii) Each small group presents the unit they designed to the class for discussion and then leads the class activities. The activities are videotaped. Class reactions toward the activities are collected. (iv) Teachers share their problems and solutions in a forum to construct explanations for their reasoning. (v) Through the exchange of ideas with peers and the teacher educator, teachers develop shared meanings that allow communication. Class discussion transforms intuitions into public products. (vi) Teachers perform self assessment and peer reflection on teaching and learning strategies in the videotaped activities.

(3) Stage 3. Independent practice

During the internship teachers should be given opportunity for independent practice in STS activities.

During the teacher development, Stages 1 to 3, formative evaluation was performed as follows.

(1) Data collection

During activities the following four items are collected: (i) Degree of participation is assessed on the basis of students' information collection and organization, frequency of comments, and quality of comments. (ii) Achievement in subject matter knowledge is assessed with paper-pencil tests. (iii) Open-ended thinking is assessed with the McDaniel scale of five thinking levels (McDaniel & Lawrence, 1990). (iv) Learning achievement is assessed in terms of the five phases of STS (Wang, 1994b; see Appendix 5). These four items were collected using the following four methods: (i) observing microteaching (in person and on video-tapes); (ii) reports of peer reflection toward microteaching; (iii) interview notes; and (iv) portfolio development (the STS modules developed, the STS module designs, the STS units developed, the unit task analyses, teachers' journals, cognitive maps, and evidence of learning achievement).

(2) Data analysis

The collected information (observation, videotapes, audio tapes, written materials) are analyzed, organized, and induced to determine the abilities constructed by the learners from that particular activity. An interpretive research methodology is used to analyze the changes in the STS related knowledge, skills, values, problem-solving ability, and teaching practices of a teacher through an STS unit development.

The professional capability of the teacher is evaluated by the usefulness of the units designed when used with peers, with respect to how well they promote (1) learning achievement, and (2) professional capabilities. If a unit is found to be useful, then the teacher development is effective.

(1) Learning achievement

Research data (Wang, 1997; Wang & Liu, 1995; Wang & Tsai, 1994a; Wang & Yu, 1994) showed that after participating in the STS activities of this model, with the aid of scaffolds, almost all teachers advanced to higher levels of thinking, becoming able to present ideas on the STS issues. They gained deeper understanding, problem solving ability, creativity, and appropriate social values. There were strong positive correlations, expressed by percentage consistencies, among degree of participation, paper-pencil tests, levels of thinking, and levels of learning, which demonstrated satisfactory learning achievement.

(2) Professional development

The STS teacher development was found effective (Wang, 1997a) by analyzing the following: (i) the unit developed at the entry level and the improved unit at the exit level; (ii) the unit task analysis and interpretation made by the teacher at the entry and the exit levels; (iii) learning achievement; (iv) the peer reflection reports on micro and class teaching performances; (v) video-taped activities; and (vi) the researcher's observation and interview documents.

The research studies indicate the model improved the participants' professional performance (Wang, 1993, 1997; Wang & Hsieh, 1997a, 1997b; Wang & Tsai, 1994b).

V. A Set of Performance Criteria for STS Teacher

Effective science teachers have the ability to integrate their knowledge of science content, curriculum, learning, teaching, and students. Teachers should use their knowledge of learning to make effective decisions about learning objectives, teaching strategies, assessment tasks, and curriculum materials (National Research Council, 1996). In addition to the professional abilities of effective general science teachers, STS teachers must clearly understand the STS philosophy and teaching goals. Also, they must have STS knowledge, metacognitive skills, and STS professional ability to deal with issue-oriented and learner-centered learning. Qualified STS teachers are viewed as a category perceived to have a family resemblance to one another (Sternberg & Horvath, 1995). STS teacher performance criteria which were induced from job analysis, direct observation, interviews, and portfolios, including video-taped STS activities, were the following (Wang, 1996b, 1997a): (1) use local resources to design and use appropriate STS modules having a high degree of self-modification; (2) promote situated learning in an authentic holistic context; (3) arrange activities to cultivate students' habits of mind (i.e., self-regulation, critical thinking, creative thinking, and readiness to act on STS issues); (4) use guided instruction before independent practice and arrange learning in proper sequence; (5) be able to provide instruction appropriate for capabilities and learning styles of students; (6) organize students for effective learning; (7) promote multidimensional thinking ability and problem-centered constructivist learning; (8) prepare appropriate evaluation activities; (9) provide students with specific evaluative feedback; (10) communicate effectively with students and encourage them to ask questions; (11) monitor learning progress closely and adjust teaching strategies such as scaffolding, cuing, questioning, and fading; (12) demonstrate metacognitive skills and sensitivity in relating to learning goals with critical, ethical, and world views; (13) promote cooperative learning including mutual stimulation and recognizing good points of others; (14) exhibit enthusiasm toward students and teaching, expect learners to achieve well, and provide an active and a positive learning climate; and (15) act as teacher/learner/researcher through feedback and self-regulated learning strategies.

VI. A Performance-based Certification Method for STS Teachers

Largely in response to dissatisfaction with some traditional fact-oriented and multiple-choice tests, performance-based certification methods have been developed and used for teacher licensure and others. This type of certification emphasizes testing complex teaching knowledge and skills in the real class context in which they are actually used (Swanson, Norman, & Linn, 1995).

This project has developed performance-based certification methods for STS teachers on the basis of STS teacher performance criteria. Performance-based certification criteria and guidelines are developed in the forms of printed and video materials which are used to train evaluators to ascertain inter-rater reliability. Evaluation by licensure is summative and based on evidence in a portfolio format provided by teachers with pieces of evidence relevant to a set of stipulated criteria, collected during one or two years of a professional development program (Wang & Hsieh, 1997a, 1997b), coupled with actual teaching observations and interviews by licensures. The portfolio is developed in a value-added process. Through the portfolio, one can review growth and achievement, the ability of teachers to reflect on work, and the ability to establish goals for future learning to meet the certification criteria. The portfolio includes a commentary in which the teacher reflects on his or her teaching as documented for formative evaluation. The portfolio identifies areas for professional development of that teacher: (1) a commentary of the real teaching context for learning and teaching; (2) modules prepared by the teacher describing learning tasks, learning environments, analyses of teaching, anchoring, scaffolding, and learning across a series of activities as well as plans for each of the individual activities in the series; (3) assessments of student learning outcomes across several learning activities, including a commentary; and (4) any additional information the teacher believes represents his or her work as a teacher.

Steps in the performance-based certification process in this study are as follows: Step 1. Teacher's self-evaluation developed in a portfolio format. Step 2. Teachers provide portfolios to licensure. Step 3.

Portfolio conference. The evaluator reviews the portfolio with the teacher (evaluatee) examining his or her professional growth based on the set of stipulated criteria. Step 4. The evaluator assigns the teacher (evaluatee) an STS topic for class observation. Teachers are evaluated through: (1) STS modules they prepare; (2) oral presentation of ideas behind their module design; (3) class teaching or microteaching performances on a unit in the module; (4) students' learning outcomes; (5) peer teachers' assessment; and (6) an interview by evaluators (Wang, 1997).

Through an actual teaching observation, the evaluators expect to see how efficiently the teacher communicates with students, monitors learning progress, and demonstrates metacognitive skills to achieve learning goals (Criteria 10-14).

VII. Conclusion

There are many issues in teacher education with little agreement among authorities. Yet all of them agree on some ideas: (1) Teacher development is a necessary component of teacher certification. (2) Supervision must be ongoing for teacher development. (3) Evaluation is a rigorous process. (4) Evaluators must be skilled and trained. (5) All affected parties must be involved in the evaluation process. (6) The criteria for judgment must be defined, communicated, and understood by affected parties (Stanley & Popham, 1988). As the National Science Education standards (National Research Council, 1996) in the USA indicates: "Becoming an effective science teacher is a continuous process that stretches from preservice experiences in undergraduate years to the end of a professional career. Science has a rapidly changing knowledge base and expanding relevance to societal issues, and teachers will need ongoing opportunities to build their understanding and ability."

Core training should be provided to all teachers to assure successful and lasting instructional enhancement efforts. In this project, the curriculum framework developed provides a way of thinking for teacher educators and/or teachers to identify, select, organize, and sequence STS activities for professional development. From a set of-our action research studies, we have observed that novices need guidance and professional development is more efficient using anchored, scaffolded, and independent practices with formative evaluation. A set of performance criteria of STS teachers was identified from interpretive research studies for which data were collected from classroom observations, in-depth interviews, teachers' journals, and portfolios. The nature of criteria-based performance assessment is such that evidence must be gathered showing that the candidate meets the standards consistently. A one-time assessment of performance is inadequate (Ambach, 1996). The STS teacher certification method is based on evidence in portfolio format provided by teachers with pieces of evidence relevant to a set of stipulated criteria, collected during one or two years of a professional development program, coupled with actual teaching observations and interviews by evaluators.

The performance-based STS teacher education thus can link teacher development and certification. The system can improve instruction for STS learning, identify qualified teachers, and stimulate domestic educational reform. The author believes the findings can be used in teacher development and certification in general.

Acknowledgment

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Appendix:

Components of the Curriculum Framework

(1) Rationale for STS learning

In some traditional schooling, learners can transfer only a little of their learning to new situations (Wheatley, 1991). Experiencing in a real world situation is the fundamental way for educating citizens who take up responsibility in promoting social prosperity and handling life-related problems. STS literacy cannot be cultivated by teaching methods of the cookbook type. Learners must not only learn the elements needed but also take combined uses of these learning elements to solve newly encountered real life problems.

(2) Learning goals and elements (See Fig. 3)

(3) Major STS concepts and assumptions

Taken in part from Chemistry in Community (ChemCom) (American Chemical Society, 1988).

(i) Science and technology have contributed in changing the type of society, advancing civilization, and promoting prosperity. (ii) Wise resource management on the planet earth aims at maximizing both short and long term benefits while minimizing environmental and human health burdens/risks/costs. (iii) Many complex problems can be made manageable by breaking them into simpler subproblems or components. (iv) Learners may become better citizens if they are given opportunities to (a) learn and apply fundamental scientific concepts and methods, and (b) practice group decision making skills in cooperative learning. (v) The learners understand themselves as interdependent members of society and an ecosystem of nature. (vi) Learners must cultivate abilities in decision making. (vii) STS activities arouse learners' interest, promote career awareness, and emphasize careers in science and technology they might pursue. (viii) STS activities help learners develop and maintain effective mental habits such as self-regulating, critical, and creative thinking and learning. (ix) STS activities develop substantive understanding and broad fundamental concepts, which cut across all disciplines such as system, interaction, relativity, change, stability, and equilibrium. (x) The present state of knowledge about any given STS issue is likely to contain some imprecision, inaccuracy, and uncertainty. Society must act upon the best available information with the understanding that additional information may call for subsequent reevaluation of a previous solution.

(4) A procedure for developing learning units and modules (See Fig. 4)

(5) Learning phases

Five learning phases were synthesized by Wang (1994b) based on the literature (Sia, Hungerford, & Tomera, 1986; Hines, Hungerford, & Tomera, 1987; Marzano, 1992; Waks, 1992). Phase 1. Awareness: Positive attitude and awareness of issues. Phase 2. Understanding: Acquiring and integrating knowledge. Phase 3. Proposing solution with explanations. Phase 4. Responsible action: using knowledge meaningfully. Phase

5. STS literate creative personality: productive habits of mind.

(6) Procedure for professional development (See Fig. 5)

(7) Types of STS activities

(i) Information search, (ii) STS module design (including simulation), (iii) Brainstorming, (iv) Mapping, (v) STS game/play, (vi) Role playing, (vii) Debate, (viii) Discussion, (ix) Decision making, (x) Problem solving, (xi) Field experience, and (xii) Experimental (inquiry) investigation.

(8) Learning activities

(i) Study science and/or social science concepts. (ii) Conduct library research. (iii) Secure data and information from government and private agencies. (iv) Collect data from experimental inquiry. (v) Use social science research techniques such as questionnaires. (vi) Analyze information and use data to propose alternative resolutions or the issue. (vii) Weigh the pros and cons of each resolution. (viii) Clarify values. (ix) Select a resolution and decide courses of action. (x) Decide which actions individuals or members of a group might take and carry through with plans, action, and evaluation.

(9) Instructional strategies (anchored and scaf-folded)

(10) Assessment strategies

(i) Group and individual presentation, (ii) Interviewing students and groups of students about project design, (iii) Observing students in role playing and simulations, (iv) Written reports, (v) Student journals, (vi) Student action plans, (vii) Standardized achievement tests, (viii) Criterion referenced tests, (ix) Home work, (x) Home tests, (xi) Extended problem solving projects, (xii) Field investigation, (xiii) Essay examination, (xiv) Multiple-choice item assessment, (xv) Cognitive maps, (xvi) open-ended thinking assessment, and (xvii) Portfolio.

(11) Performance criteria of STS teachers (See Section V)

(12) Representative modules and guidelines for selecting STS activities

Representative modules should cover global, national, local, and life-related issues including representative types of STS activities.

The learning activity designs are characterized by the following features: (1) student centered; (2) problem centered; (3) based on student prior knowledge; (4) linked to the world outside the classroom; (5) linked to social, cultural, and environmental issues; (6) cultivate higher order thinking for decision making and problem solving; and (7) encourage individual as well as cooperative learning to promote ethics and social values.

It is important that the learning can improve views on STS issues and that learners are encouraged to (1) link STS issues with other knowledge within a discipline, with other disciplines, and with social and global problems, (2) understand the overall structural relationships among the elements in the issue, (3) understand the relationships among the prerequisites already known and the present learning elements, (4) apply the process skills already learned to a new topic, identify similarities and differences, and generalize, and (5) build cognitive networks to perceive, define, analyze, support, and elaborate on a situation.

After the learning activities the teachers will be able to (1) select STS issues and contents, (2) determine the most appropriate fit for STS issues in a curriculum, (3) develop an integrated approach for teaching STS issues, and select the STS materials, (4) select strategies of instruction and assessment, (5) construct STS concepts and positive attitudes toward science and technology, (6) develop the skills of analyzing STS issues, and (7) assess the design of study units.

師資培育與師資檢定之連結

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摘　　要

作者開發一種以實作爲基礎的STS教師培育系統，其係將師資培育與師資檢定相連結並由下列四個要素所構成：(1)STS師資培育課程架構；(2)建構主義模式之STS師資培育與形成性評量；(3)一套的STS師資實作基準；(4)實作爲基礎的STS師資檢定方法。作者自從1993年以來，在實際教學情境中，從事一系列行動研究而開發此等要素。此課程架構提供一種思考方式，使師資培育者與教師們尋找、選擇、組織及排列STS活動，作爲教師們專業發展之依據。本研究發現生手需要輔導；教師若經過錨式、鷹架方式，發展專業能力後，從事獨立教學，同時亦實施形成性評量，則較爲有效。STS教師之實作基準是在一系列的詮釋性研究，經由教室觀察、深度晤談、教師之教學日記和教學歷程檔案等資料歸納而得。STS師資檢定方法根據上述實作基準，由檢定者(1)考核教師所提供的教學歷程檔案中的證據，(2)觀察其實際教學，並(3)晤談而評鑑。教師所提供的證據是該教師在一至二年師資培育期間，根據STS教師實作基準而收集者。

此STS教師培育系統能改進STS教學，篩選勝任教師，並促進我國教育革新。

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Continually Expanding Content Representations: A Case Study of a Junior High School Biology Teacher

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ABSTRACT

The purpose of this study was to explore how an experienced biology teacher continually expanded representations in her teaching career. Participant observation, interviews and various related documents were used to collect data. The findings were presented in terms of five assertions: (1) The evaluation of representations made the teacher feel the need for change. (2) The teacher arranged representations in an expanding sequence. (3) The teacher searched for data to form alternative representations. (4) New representations resulted from modification, specification, combination, or invention. (5) Representations were modified through pretests and classroom teaching. The incompleteness of representations made the content transformation act a dilemma. As Lucy managed dilemmas, she reflected on her representations and continually expanded the representations. This process was based on her extensive knowledge, and this knowledge was developed during the process. The implication of this study is that science teachers can reflect on their representations to promote professional growth.

Key Words: content representation, professional knowledge growth, interpretive research

I. Introduction

The entrance examination has become a major factor influencing the teaching practices and quality of learning in junior high schools in Taiwan. In order to help students get high scores on the entrance examination, teachers often put emphasis on repeated exercises that aid the retention of facts. The content of the curriculum is usually based on textbooks and the questions asked on examinations. Students' learning life is full of examinations and memorization of facts from textbooks.

Increasingly, people have begun to reflect on the educational quality of primary and secondary schools and calls for educational reform have been proposed. They emphasize the importance of learning equality for all children and are asking for a higher quality learning environment. Despite this situtation, why do teachers still slide into traditional routines and repeat the things they have done before? Can teachers develop critical ways of understanding their teaching contexts and alter their teaching practices to enhance student learning?

Studies have proposed that content transformation is the central intellectual work of teaching (Shulman, 1986, 1987). To foster understanding of science, successful teachers cannot only have an undrestanding of a concept, principle, or theory of science. They must develop the ability to represent the content in different ways to communicate knowledge to their students. Through a lens of representation, this study explored how an exemplary junior high school biology teacher, who had succeeded in remaining enthusiastic over the course of a 13-year career, continually expanded her repertoire of representations to help her students learn biology. Representations are defined in this article as ways of representing the subject to make it comprehensible to students in real teaching contexts.

Examining teaching in terms of representations instead of methods or strategies is intended to focus attention not just on activities of teachers and students in a classroom but on the relationship between activities and the science knowledge taught. The concept of representations illuminates the wholeness of teaching content and strategies (McDiarmid, Ball, & Anderson, 1989), which both influence student learning. The notion of representations also explains subject-specific properties of teaching (Shulman, 1986). Teachers need to consider different issues in different subject mater when they transform subject matter and select and evaluate representations. Using representations appropriately demands specific knowledge (McDiarmid *et al.*, 1989).

The results can contribute to a better understanding of the nature of life-long learning in science teaching, especially for science teacher educators and science teachers who believe that continual learning from teaching practices plays an important role in professional growth.

II. Review of Literature

Within the learning-to-teach literature, researchers examine the developmental concerns of student teachers (Fuller, 1969), developmental stages (Berliner, 1988; Kagan, 1992), their roles and beliefs (Brickhouse, 1990; Duffee & Aikenhead, 1992; Munby, 1984, 1986; Tobin, 1990a, 1990b) and their knowledge (Geddis, Onslow, Beynon, & Oesch, 1993; Lederman, Gess-Newsome, & Lantz, 1994; Shulman, 1986, 1987; Wilson, Shulman, & Richert, 1987). Researchers have also tried to understand the nature of beginning teachers' critical transition from college students to school teachers and support beginning teachers' teaching needs.

Most of the above literature puts emphasis on beginning teachers' professional growth. However, learning to teach is a lifelong process and as one teaches, one learns (Feiman-Nemser, 1983). Passing the survival stage does not guarantee that teachers will successfully continue to grow. The stage theories do not imply that earlier stages lead naturally to later stages (Grossman, 1992). In a review article Britzman (1986) described the way in which teachers' personal histories interacted with common myths of their culture to maintain current teaching practices. She concluded that without a critical perspective, student teachers would lose their intention to enhance the potential of students and slide into a cycle of repetition of other teachers' teaching. Feiman-Nemser & Buchmann (1989) conducted interviews and classroom observations with six teacher candidates throughout two years. They reported that teachers were satisfied with their teaching and became less likely to criticize the prevailing norms after mastering the socially patterned school routines. Some teachers in this study paid attention to management problems, but didn't necessarily learn how to teach.

Science education researchers have indicated that several constraints shape science teachers' development or prevent them from changing in their teaching environment (Abell & Roth, 1992; Brickhouse, 1993; Lantz & Kass, 1987; Loughran, 1994; Tobin, 1990a, 1990b; Tobin, Briscoe & Holman, 1990; Tobin & Gallagher, 1987; Wallace & Louden, 1992; Wood, 1988). These constraints included institutional and social expectations, accountability via test scores, curriculum, equipment, support, time, knowledge, experience, and beliefs. These researchers also suggested that critical thinking or reflection is an important first step if teachers are to change and improve their teaching. Sharon, an elementary teacher of mathematics and science, was a participant in the study of Tobin *et al.* (1990). Through reflection on her interactions with colleagues and students, Sharon perceived a problem with the curriculum. She confronted constraints and sought the support she needed. Sharon became an agent for change for herself and for the colleagues and children with whom she worked.

Researchers have acknowledged the importance of content transformation in teaching. What is the theoretical framework of the process of transformations? In "Knowledge Growth in a Profession Project," Shulman and his associates (e.g., Carlsen, 1991; Hashweh, 1987; Shulman, 1986, 1987) focused on how the subject matter knowledge of novice teachers grew and changed over time. As they observed and conversed with teacher collaborators, they found that novice teachers struggled to develop many different ways to explain the content of their disciplines in order to help their students learn (Shulman, 1986, 1987). They constructed a theoretical framework for understanding the reasoning process of transformations. To accomplish transformations, teachers draw on pedagogical content knowledge. Pedagogical content knowledge is "a blend of pedagogy and content which included an understanding of how the topics in instruction were related and how they were most effectively organized and presented in the classroom context" (Shulman, 1987). Pedagogical content knowledge also includes knowledge of alternative representations of a particular subject and knowledge of understanding and misconceptions of a subject. This knowledge is developed in a cyclic process in which teachers comprehend, transfer, instruct, evaluate, reflect, gain new comprehension, and transfer again. The transformation process involves four subprocesses: interpretation, representation, adaptation, and tailoring to student characteristics (Shulman, 1986, 1987).

In science teaching a growing body of recent research has utilized Shulman's concept of pedagogical content knowledge. Geddis *et al.* (1993), for example, described two student teachers' attempts at teaching the subject of chemical isotopes. The researchers collected data by interviews and classroom observations. In the course of analysis, examples of four distinct categories of pedagogical content knowledge were articulated. Knowledge of learners' prior knowledge, effective teaching strategies, alternative representations, and curricular saliency were all important components of the pedagogical content knowledge that beginning chemistry teachers needed to acquire. The researchers claimed that the components of pedagogical content knowledge played important roles in the task of effective transformation.

Most of these studies beginning with Shulman's suggested that pedagogical content knowledge plays important roles in transformations of subject matter. Researchers have tried to articulate the concept of pedagogical content knowledge by exploring knowledge growth in student teachers. They paid little attention to the dynamic aspect of pedagogical content knowledge and to continual growth in experienced teachers. Interviews and observations were major methods of collecting data. However, many of the studies were conducted in laboratory settings (Hasweh, 1987; Marks, 1990). Transformations are complicated in real teaching contexts. There are many factors that influence transformations of subject matter. It seems that a true picture of a teacher's expanding process of representations can only be derived in the context of a naturally occurring classroom setting.

This study collected data through extensive classroom observations, teacher interviews, and review of documents. It was sought to explore the process through which an experienced biology teacher continually expanded her representations and promoted growth in real teaching contexts. This process was not the trial-and-error approach that beginning teachers adopted. The teacher's goal of expansion was not a struggle to survive, but to renew and search for the most effective way to attain worthwhile goals.

III. Method

1. Selection of Teacher

The teacher in this case study was selected from a list of candidates containing exemplary biology teachers nominated by science education experts and scholars. An observation of potential participants' classroom teaching was also conducted to select a teacher who displayed expert characteristics in biology teaching and an expansion process of content representations. "Criteria of Excellence: Biology Teachers of Junior High School" (see Lin, 1994) describes expert characteristics in biology teaching as an accredited subject. The teacher and the school administrators were asked to cooperate. Through this procedure the teacher, Lucy, was selected.

2. Participant and Context

Lucy, a female teacher, had been a biology teacher for 13 years. She had won many awards. Some examples were the Taipei Municipal Annual Outstanding Teachers' Award, Award for Outstanding Achievemnt in the Taipei Municipal Science Fair, and Award for Outstanding Achievement in the Tiapie Municipal Teaching Aids Presentation.

Lucy worked in a school located in Taipei City. It was a co-educational public school where most of the students' families were of a working-class background with middle socioeconomic status. There were five biology teachers and 21 seventh grade classes in the school. Thirty-eight students, 18 boys and 20 girls, of mixed abilities were in the participating biology class.

3. Data Collection

Data was collected by means of observation, teacher interviews, and review of documents. Observations were made during twenty-eight 50 min lessons of the participating class, which were held continuously from March to June of 1992. The teacher interviews regarding content representations were conducted before and after each individual observation. An occasional lunch or tea time was arranged so that Lucy could be interviewed in a more casual setting. All observations and teacher interviews were video-recorded or tape-recorded. Related documents, including the teacher's lesson plans, notes, transparencies, work sheets, maps, charts, pictures, and tests, were preserved with photocopies or photographs.

4. Data Analysis

The data base consisted of field notes and transcriptions from observations, interviews, and related documents. Excerpts were taken from the field notes and transcriptions to describe teaching practices and tentative assertions concerning the practices. The excerpts were discussed with Lucy regularly throughout the study to confirm the significance of her behavior, and Lucy was also asked to comment on any ideas that she thought to be misrepresented or incomplete. Then, all the excerpts were coded and classified. Major categories included forms of content representations, processes of expanding representations, and teacher knowledge. Within each category were many subcategories, in the form of content representations such as metaphor, discussion, explanation, hands-on activity ... etc. All the excerpts were examined for trends and frequency. At this time tentative hypotheses about the processes of expanding content representations were formed. Then the specific trends were explored and more concrete hypotheses were formulated and tested with subsequent coded data from different data gathering methods. Contradictory data was sought to revise the hypotheses. Reliability check for coding were conducted with other researchers. (For more information on the data analysis, see Lin, 1994.)

IV. Findings

The findings of this case study are presented below in five assertions.

1. Assertion 1. Evaluation of Representations Caused Lucy to Feel Dissatisfied and Think There Was a Need for Change.

Lucy constantly changed her representations for the same concepts throughout her teaching career. She explained the used representations during interviews. Why did she change them? Lucy described her motivation to change her representation of "relationship between genes and traits" as follows:

> I had used different color glasses to interpret the relationship between genes and traits for many years. One day I stood in the back of the classroom, and I saw that the color of two overlapping red glasses was deeper than the one made by a transparent one and a red one. I was shocked by this phenomena. It might mislead students into thinking that the traits of homogeneous and heterogeneous combinations were different. I decided to correct this immediately.

If Lucy did not know the disadvantages of her representations, she would not feel the need to change them. There was not a repertoire of representations.

What was a "good" representation? For Lucy all representations had to be feasible in the teaching context. A representation also had to provide authentic information and be helpful to student learning. Lucy tried her best to transfer content but in practice circumstances were too complex to achieve all criteria simultaneously. Scientific information or scientists' explanations were always too technical for her students to comprehend. Though stimulating students' learning interest and making learning easier, transformations could not avoid distorting the meaning of the scientists' knowledge. For example, Lucy sometimes gave explanations in terms of purposes and intention (e.g., the male peacock blows its tail open to impress and attract the female) to help students learn. She said, "These anthropomorphic explanations may mislead student learning. Some students will think that animals, like human beings, have intentions."

Reflection on representations made Lucy see the characteristics of her teaching. Lucy knew that different representations could present different facets and dimensions of science. She said that some representations were closer to scientists' knowledge and some were easier to learn. She also mentioned that different representations could attract students' attention and meet individual needs. Lucy stated, "Every representation has its own advantages and limitations. None of them are perfect." This incompleteness of representations made Lucy feel they were unsatisfactory and there was a need to create other representations.

2. Assertion 2. Lucy Arranged Representations in an Expanding Sequence.

Every representation had its own advantages and limitations. It seemed that there was no representation which could represent all the meanings that Lucy wanted to present. Which one would Lucy choose to present? This was a dilemma. Presenting multiple representations for one concept was the strategy that Lucy selected to deal with this dilemma. Lucy said,

> I try to transform the content into different forms just like a cook who use the same meat or vegetables to prepare many different dishes. My students can select helpful forms to aid their understanding just as customers choose their favorite dishes to eat. No matter which one or ones they choose, they all learn the concept.

However, the expanding process was time consuming. Lucy could not transfer all concepts into multiple forms at the same time. Therefore she arranged them in a sequence to form alternative representations that would help students learn.

Lucy gave priority to forming multiple representations for difficult concepts. She noted students' common difficulties in learning biology. Most of these concepts were within genetics, cell biology, and evolution. The common characteristics of these difficult concepts were complexity, having too many terms, being abstract, and not being observable with the naked eye.

About the unit of "genetics" Lucy said,

> Genetics is one of the difficult topics for the students. Students need the concepts of mitosis, meiosis, chromosomes, genes, sexual reproduction, asexual reproduction, genotypes, phenotypes, probability, ... etc. Students seldom have had a chance to observe these phenomenona before. These concepts are all difficult to learn. In particular, most of my students do not develop the ability to manipulate problems of probability.

As a consequence, it was a priority that difficult concepts be presented in different ways. For example, when teaching "mitosis", Lucy explained six representations. They were teacher explanation of the rules of mitosis, hands-on activity with mitosis cards, illustration of onion mitosis, illustration of fish mitosis, reading paper, and discussion. Lucy used about 70 pictures in the above teaching activities. She emphasized visual learning and hands-on activity in this case.

3. Assertion 3. Lucy Searched for Data to Form Alternative Representations.

Lucy required a body of knowledge that would contribute to her expanding collection of representations. Examples were knowledge of subject matter, students and learning, curriculum, teaching media, alternative representations, and context. She obtained this kind of knowledge from her personal learning experiences, teaching experiences, textbooks, other teachers, volunteer worker training, in-service training, and students' responses.

Subject matter knowledge was the content of representations. Lucy had received a bachelor degree in biology. She had also earned some master level credits in biology. Lucy already had extensive knowledge of biology. Most of the subject matter knowledge cam from her personal learning experiences. However, Lucy did not think that she had enough subject matter knowledge for teaching secondary school biology. She said, "Because of the diversity of biology, I cannot answer all questions students ask. I need to check it out in books." She told stories of biologists, for example Charles Darwin, Louis Pasteur, and Gregor Mendel. Lucy emphasized environmental issues in her biology class. She showed an environmental room filled with ten environmental problems occurred at Taiwan. This kind of knowledge did not come from her formal education but rather from books, journals, newspapers, volunteer worker training and in-service training. Lucy's subject matter knowledge, especially about science-technology-social issues, everyday life, and stories of biologists, was developed through the process of expansion.

Lucy needed knowledge about students and learning to communicate effectively. Lucy was concerned about what students knew about science knowledge, reasoning skills, and life experiences. When teaching "genetics", Lucy reviewed related topics in elementary school to find out what her students had learned. She asked a mathematics teacher about what her students had learned about probability. She also interviewed some students about the concepts of genetics. When these were ascertained, she designed activities for students in order to relate the new content to the old.

Lucy required knowledge concerning intended objectives, activities and textbook problems. She selected the proper content, put it in sequential order, linked concepts from different topics or lessons, and manipulated the pace. Most of this kind of knowledge came from her teaching experience, textbooks, and teacher's manuals.

Knowledge of contexts made Lucy adjust her ideals to the situation in the real practice environment. Lucy was familiar with the expectations held by society, the school, parents, and students after thirteen years of teaching. For example, the expectation of high achievement in examinations influenced her instructional emphasis and test content and made her increase test frequency. She knew the hardware and software in school and out. This had an impact on Lucy's decisions to use materials and media.

Knowledge of alternative representations allowed Lucy to conduct lively transformations. Lucy actively attended teaching conferences, in-service training, and volunteer worker training to get new ideas. She also discussed her teaching with her colleagues and teacher friends and thereby change her representations.

Lucy knew who and where would provide resources for teaching, and she would learn new methods and knowledge for improving her instruction when she felt the need. University libraries, science museums, educational data centers, botanical gardens, zoos, and national gardens were the places where she or her students usually visited to get information. Lucy also built good relationships with university professors, consultants of teachers' in-service training centers, and colleagues who could provide assistance and suggest alternatives to help solve teaching problems.

4. Assertion 4. New Representations Resulted from Modeification, Specification, Combination, or Invention.

If Lucy felt the need to change her representations, she tried to modify her representations for different students and teaching conditions. There were two kinds of modifications: inter-form modifications and intra-form modifications. The same content was transferred to different forms in the inter-form modification. For example, because of difficulty in handling students' responses, Lucy changed an illustration of "flowers" with the aid of slides to a student discussion with the aid of pictures. Lucy would only add, delete, or replace content and not change the form in intra-form modification. Giving students a familiar frog instead of an unusual salamander as an example of the amphibians was a case of intra-form modification. Modification seemed to be the most economical way to increase the effectiveness of representations.

Besides modification, Lucy also tried to create new representations. A new one could result from a specification, combination, or invention.

A specification was when Lucy borrowed the form of an existing representation from instruction in other subjects. Then she transformed a biology concept into the same form to generate a new representation. For example, a form Lucy used to help her students construct the concept of "classification of living things" came from a professor's representation for "shape". Lucy said,

> I taught the "classification of living things" according the content in the textbook for many years. I pointed out characteristics and names of animals and plants for each kind. Students were always confused by the names and characteristics of so many living things. There were communication problems between the teacher and students and between students and students. What students needed to do was to memorize ... I remembered a lively professor who showed us many different shapes but only answered yes or no questions. We all learned the classification scheme, characteristics and names of the shapes. Why shouldn't I use this form to teach "classification of living things"? I prepared pictures of different living things and showed them in my classification class. I asked students to raise questions that could be answered by yes or no to help them construct the classification scheme.

Lucy would combine representations to generate a new one. In the "mitosis" unit, Lucy combined a teacher demonstration of a model of mitosis with a student discussion on the characteristics of mitosis to form a student manipulation of pictures of mitosis. Combination always occurred in the condition that Lucy taught the same or related concepts.

Lucy also invented new representations. Lucy described the development of her representation of the "relationship between genes and traits" as the following:

> After deciding to change the representation of "relationship between genes and traits", I thought it over all day, every day, even while walking and during daily activities. One day an idea flashed into my mind. 'Ah ha, I got it' I said.

The expanding process took time. Sometimes, Lucy did not have any new ideas and her thoughts stayed in a latent stage. She did not like her strategy of repeated exercises to help students to learn the concept of "probability in genetics", but she did not know of any better strategy. Therefore, she concluded that repeated exercises were her best choice and presented them in her teaching. This did not mean that Lucy gave up. She worked hard to struggle with it.

5. Assertion 5. Representations Were Modified Through Pretests and Real Teaching Practices.

To make sure of the feasibility of new representations, Lucy would ask some students to do the tasks in a simulated teaching environment before using them. She observed students' responses and asked questions about new representations. Then she tried to change them. As an example, Lucy asked five students to do a worksheet on "asexual and sexual reproduction of plants" while out of class. She collected information about its readability and how much time was needed. According to students' reactions, she modified some items on the worksheet.

All the above actions were still during the planning stage. Many other factors could affect the success of a representation in a real classroom. Representations must be tested by direct teaching.

Teaching behavior was a focus that Lucy evaluated when she presented a new representation in the class. Lucy said,

> Whenever presenting the new materials or activities, I always paid attention to myself. During the class I asked myself, "What will I do next? Is the explanation clear enough?" I was busy with looking for pictures or specimens that I wanted to illustrate. I spent much time on managing the class. After teaching the same topic for the second or third time, I would have enough time to be attentive to student learning behavior.

After maintaining a fluid teaching flow, Lucy turned her attention to students' responses. Lucy analyzed test results, homework, and worksheets, kept an eye on student behavior, and conducted student interviews to collect learning information. She wanted to make sure that the representation could help students understand.

Lucy reviewed her teaching behavior, the teaching context, students' behavior, classroom management, and time arrangement. Depending on her memory and feelings about classroom events, she analyzed the events and tried to find factors which influenced the success of the representations. Later she reconstructed them for future instructional action. These activities happened both during class and afterwards. While discussing "the results of Hydra's asexual and sexual reproduction", there was no student response on this topic. Then Lucy showed another four different representations to help them participate in the discussion. About this event Lucy said,

> I saw dull expressions on the faces of my students and I knew I was in trouble. I guessed that they were too tired to keep their attention on my teaching after a whole morning of classes. I repeated the same explanation again. But they still did not respond. I decided to draw a picture and gave an example to help the students understand. Then I asked them to pretend that they were the Hydra family, to state their position, and to explain why they hold this position. This evoked a favorable response.

This was an example of Lucy's instructional action which resulted directly from her reflection during teaching.

Lucy's colleagues also participated in the evaluation of her representations. She always introduced and discussed new representations with her colleagues. They would give her feedback, such as if they liked it or disliked it and the reasons why.

V. Discussion

Throughout the cycle of teaching and reflection on representations, Lucy expanded her repertoire of instructional representations. This was a continuous process of learning to teach.

Coming from a family of teachers, Lucy looked forward to being a teacher and considered being a teacher her number one choice. For her, teaching was an important thing which would influence thousands of students. She thought that teachers played a key role in learning and could make a different world for students. She had high expectation of herself. She believed that a good teacher must be a learner of how to teach, and no man was born a successful teacher. Lucy had rich resources for learning to teach. Personal learning, teaching experience, textbooks, other teachers, volunteer training, in-service training, university professors, library services, consultants at teachers' in-service training centers, museums, parks, and students' responses were all probable sources of her knowledge base. Her belief in learning how to teach and rich resources for learning how to teach helped her knowledge develop continually.

For Lucy, an ideal representation was close to the scientific facts, was comprehensible to students, made learning interesting, and was feasible in the teaching context. However, teaching circumstance were too complex to achieve all criteria of "good" representations simultaneously. Reflection on the criteria made her believe that every representation had limitations. It was like a double-edged sword, as it helped student learning, it might also lead to misunderstandings (Duit, 1991). The incompleteness of representations provided space for her to continually expand her representations.

Lucy needed to transfer the subject matter into forms accessible to students and to represent the content as authentically as possible. This made the transformation act a dilemma, as other researchers have described (Geddis *et al.*, 1993). Developing and presenting multiple transformations was a strategy she used to deal with the dilemma. Then she could compensate for the limitations of representations. In the meantime she could show the many facets of science and meet the needs and interests of different students. As Lucy dealt with dilemmas, she reflected on her own teaching and promoted her own professional growth. This kind of growth seemed to be the same as that in Tomanek's (1994) study.

Shulman (1987) indicated that transformations require a combination of preparation, representation, selection, adaptation, and tailoring to student characteristics. Among these processes, representation seemed to be the most obscure and difficult process of forming new representations. We know little about "how to represent". The findings in this study show that this "how" was modification, specification, combination, or invention in Lucy's case. The process proceeded from Lucy's extensive knowledge; her knowledge also developed during the renewing process. Lucy's expanding representations and her knowledge hold a dialectic relationship. This seems to be the same as Clark and Peterson's (1986) description.

Besides knowledge, time, effort, resources, and support, creativity was also a key factor in Lucy's renewal of her representations. Invention, as knowledge reorganization (Schon, 1983), showed the creative side of the teacher's thinking. It allowed Lucy to used only simple and inexpensive materials and easily arrive at procedures to represent concepts for special purposes, students, and contexts. This renewing process not only solved Lucy's teaching problems, but also helped her enjoy the self-actualized feeling that accompanied the process of creation. These inner and outer motivations seemed to be the force driving Lucy to renew representations continually.

Facing the existing environment, Lucy knew how to balance her ideals with the expectations held by the society, school administrators, parents, and students; how to utilize hardware and software of the school and community to enrich her representations; and how to ask support from colleagues, school administrators, and the community for biology teaching. Teaching context shaped Lucy's forms of representations but did not prevent her from improving them. For Lucy these components did not seem to act as constraints in the same manner as beginning teachers' construction (Abell & Roth, 1992; Brickhouse, 1993; Tobin & Gallagher, 1987). They acted more like learning conditions where Lucy could test the feasibility of her new representations. Sometimes, they seemed to act as a facilitator that pushed Lucy to use her creative capacity toward solving teaching problems.

VI. Implication

This case study of an experienced biology teacher illustrates that reflection on representations can be an effective approach for professional growth. A teacher's thinking is often a reflection of her representations. The incompleteness of representations opens spaces for her to continually expand representations. Through the expanding process the teacher demonstrates the dynamic, flexible, content specific, context dependent, interchangeable, incomplete, and personal teaching style of representations. This process is based on the teacher's extensive knowledge, and knowledge is developed during the process. The results enable us to further understand the nature of a teacher's lifelong learning.

Perhaps this suggests that teacher educators, especially those involved in in-service education, can encourage teachers to take charge of their own professional growth by helping them to build criteria of "good" representations for reflecting on their representations. Discussion with teachers about reflection on criteria of "good" representations should be illustrated in terms of dilemmas. Helping teachers focus on the dilemmas may empower them to reflect on their teaching, identify dilemmas, locate resources, and manage them within themselves, rather than initiating professional growth from outside their classroom world. Science teacher preparation programs should foster reflection that enables teachers to make sense of classroom events and apply their knowledge to form representations which fit their circumstances. Science teacher educators could then provide alternative suggestions and support for those who are unsatisfied and want to make change, and those who need help.

Further research is required to articulate similar development for other teachers in the same and different subject areas.

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教學表徵的擴展：生物教師個案研究

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摘　　要

本研究的目的是探討一位資深國中生物教師，在其教學情境中，如何持續的擴展其教學表徵，以引導學生學習生物學。研究資料的收集方法包括教室觀察、教師晤談、文件收集；全程均輔以錄影、錄音以便事後分析；並以「三角校正」的方法效化資料。研究結果發現(1)個案教師評鑑教學表徵，引發其擴展教學表徵；(2)個案教師安排概念的先後次序，以建構多重的表徵；(3)個案教師收集相關資料，以擴展教學表徵；(4)新的教學表徵是個案教師進行修正、特殊化、組合或創新的結果；(5)新的教學表徵必須經過預試及實際教學的修正。由於教學表徵的不完備性，造成形成表徵的兩難性，教師面對此兩難問題時，一面反省教學表徵的適當性，同時建構多重表徵，以引導學生學習科學。科學教師在擴展多重表徵的同時，不斷的運用、學習、重建相關的教學知識。本研究的啟示是，科學教師可藉由反省教學表徵的適當性，促成教師個人之科學教學專業知識的成長，值得科學師資培育機構及相關研究者參考。

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Expert Opinions Concerning a Taxonomic Structure for the Curricular Organization of Biotechnology

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ABSTRACT

Biotechnology has been declared a "strategic industry" and made a national priority by the government in Taiwan. In this study, the opinions of biotechnology experts were investigated and a taxonomic structure describing the range and content of the field of biotechnology proposed. A modified Delphi technique was followed in this study. The study included a literature survey, design of a questionnaire, first distribution of the questionnaire, preliminary modification of questionnaire content, distribution of the modified version, face-to face expert panel discussions, and finally completion of the final version of the taxonomy. The expert panel included 11 experts at the first stage (questionnaire) and 16 experts at the second stage (expert panel discussion). The conclusions are as follows: (1) Biotechnology requires a wide range of knowledge from at least 16 disciplines, including microbiology, chemistry, and molecular biology, etc. (2) Biotechnology should cover 15 main concepts including its definition, historical development, basic knowledge, basic techniques, manipulation of prokaryotic cell genes, manipulation of eukaryotic cell genes, protein engineering, application of microbes to produce commercial products, diagnostic reagents, vaccines and therapeutic drugs, microbial degradation, downstream processes and social aspects of biotechnology. The taxonomic structure of biotechnology derived through expert consensus should allow for further development of curriculum for biotechnology programs.

Key Words: taxonomy, biotechnology, Delphi technique

I. Introduction

The term "Biotechnology" was proposed by Karl Ereky in 1919 (Bud, 1993). Since then, biotechnology has become one of the major disciplines linking basic research with industrial production. It is widely applied to areas including bioprocessing (fermentation), genetic manipulation, agriculture, medicine, environmental protection and others. The definition of biotechnology suggested by the Organization for Economic Co-operation and Development (OECD) in 1993 was: "Biotechnology is the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services" (Bud, 1993).

Greater awareness of the profound effects of biotechnology on human life has resulted in a significant increase in investment in biotechnology research and development. In order to meet the great demand for manpower in this fast-growing industry, development of a biotechnology curriculum has been recommended by experts (Hudson, 1988). However, based on the specific aim of the particular biotechnological program, the content of the curriculum could be very diverse.

A study conducted by Rinard (1986) collected data from 242 biotechnology companies. Based on the task listings and suggestions from survey respondents, he developed a model curriculum for two-year biotechnician training program. His model curriculum sought to provide sufficient background so that, with a reasonable amount of work experience, the graduates could advance to positions with increasing responsibilities. Therefore, his curriculum included *basic knowledge* (e.g. chemistry, molecular and cell biology, microbiology), *applied science* (e.g. fundamentals of instrumentation and control, industrial microbiology) and *communication skills* (e.g. technical communications).

Gayford (1987) suggested an in-service training program for teachers. The specific aim of the program was to produce a course covering aspects of biotechnology which would increase understanding of various areas of the subject, as well as encouraging the integration of biotechnology into science education for the whole age and ability range of 13-18 year-old pupils. Therefore, the content of the curriculum was distinct from that developed by Rinard. Topics included *an introduction to biotechnology, safety and management aspects of biotechnology, genetic manipulation, fermentation, tissue culture and cell culture, enzymology, downstream processes,* and *enhancement of the effects of biotechnology*.

Paolella (1991) suggested biotechnology outlines for both high school and college classes. The curriculum was designed for students who had completed a molecular genetics unit which included the structure of nucleic acids, replication, transcription and translation. The content of the curriculum included *definition of biotechnology, genetic engineering, history of biotechnology,* and *basic techniques of biotechnology* (e.g. isolation of DNA, utilization of restriction enzymes, choice of a vector in which to insert a gene of interest). The author also included a concept and V map in a model section.

Another curriculum was suggested by Glick & Pasternak (1994), this time focussing on advanced biotechnology. Based on a biotechnology course offered for over 12 years to advanced undergraduate and graduate students at the University of Waterloo in Canada, Glick & Pasternak (1994) wrote a book entitled *Molecular biotechnology: principles and applications of recombinant DNA*. The book was designed to serve as a text for courses in biotechnology, recombinant DNA technology and genetic engineering, or for any course introducing both the principles and the applications of contemporary molecular biology. The authors suggested that students who took this course should have an understanding of basic ideas from biochemistry, molecular genetics and microbiology. The curriculum included *Fundamentals of molecular biotechnology* (e.g. recombinant DNA technology, manipulation of gene expression in prokaryotes, directed mutagenesis and protein engineering), *Microbial systems* (e.g. microbial synthesis of commercial products, vaccines and therapeutic agents, large-scale production of proteins from recombinant microorganisms), *Eukaryotic systems* (e.g. genetic engineering of plants, development and use of transgenic animals, isolation of human genes) and *Regulating and patenting molecular biotechnology* (e.g. regulating the use of biotechnology, patenting biotechnology inventions).

The purpose of this study was to develop a conceptual model of biotechnology's taxonomic structure. Such conceptual model, derived through expert consensus, would allow for future development of biotechnology curricula and would be applicable to both technology education programs and biological science programs. To achieve this goal, the following research questions were addressed to a panel of experts:

(1) What are the main knowledge areas of biotechnology?
(2) What are the proper subdivision titles for each knowledge area?
(3) What are the major concepts and subconcepts under each subdivision title?

II. Methods

The research method used in this study was a modified Delphi technique (Cyphert & Gant, 1971). The purpose of using the Delphi technique was to obtain a consensus from a panel of experts within the discipline of biotechnology. The expert panel members were selected from seven research institutes. Among them were microbiologists, molecular biologists, virologists, plant physiologists, immunologists and downstream process experts.

The Delphi technique was developed during the 1950s by workers at the RAND Corporation as a procedure to "obtain the most reliable consensus of opinion of a group of experts by a series of intensive questionnaires interspersed with controlled opinion feedback." The technique was originally applied to deal with complex defense problems (Uhl, 1990). In later years it has come to be used in a wide variety of fields, including business, government, industry, medicine, regional planning and education, for a wide variety of purposes, including future forecasting, goal assessment, and curriculum planning, etc. (Uhl, 1990).

Four necessary features characterize the Delphi procedure: anonymity, iteration, controlled feedback, and statistical aggregation of group response. In this study, anonymity was achieved using questionnaires and small group panel discussions. Interaction was proceeded by two rounds of questionnaires. Controlled feedback was performed between the two questionnaires and the statistical analysis was done simultaneously. Each member of the expert panel was informed of the results of the statistical analysis and the comments of other experts. After the panel discussion, a consensus from the panel of experts was achieved. However, the greatest difficulty of using the Delphi technique in this situation was that the disciplines within biotechnology are so diverse that no one expert could be familiar with all the concepts on the questionnaire. Therefore, one or more participants', views predominated with regard to several concepts.

1. The First Questionnaire

After an extensive literature review, a preliminary understanding of the main knowledge areas, subdivisions and major concepts was established. The first questionnaire was subsequently developed on the basis of this preliminary understanding. The questionnaire was divided into two parts: The first part asked the expert panel members for their responses and comments in thirteen knowledge areas possibly relating to the field of biotechnology. The second part asked the expert panel members for their judgments and written comments pertaining to the sixteen subdivisions and concepts relating to those subdivisions. The experts were asked to rate each knowledge area, subdivision title and major concept on a five-point scale as to their degree of agreement. In addition, they were asked to give a brief written comment at the end of each subdivision.

The results of the first questionnaire were statistically analyzed and the subjects that received a negative score were adjusted or deleted on the basis of written comments. The revised questionnaire was resubmitted to the same expert panel. The experts were asked again to make judgments on the subjects before the panel discussion was held.

2. Panel Discussions

Panel discussions were held separately at seven institutes and the total number of participants was expanded to fifteen. The content and structure of the knowledge areas and taxonomy were further revised based on the results of the panel discussions. If a panelist with a response outside the consensus range failed to change his/her suggestion, he/she was asked to provide an additional statement. A final version of the knowledge areas and taxonomy was then submitted to the participants in order to confirm the consensus.

III. Results

1. Knowledge Areas of Biotechnology

Based on the degree of consensus, the experts were asked to rate each of the knowledge areas on a five-point scale. The frequency of each level agreement and total points were recorded (Table 1). The three knowledge areas Industrial engineering, Electronic engineering and Mechanical engineering obtained a score below 0. Therefore these three knowledge areas were excluded from the second Delphi questionnaire. The experts also suggested that Zoology, Plant biology, Physiology, Immunology, Animal breeding and Medical engineering should be included as knowledge areas. These suggestions were also included in the second Delphi

Table 1. Degree of Consensus on the Knowledge Areas of Biotechnology

Knowledge Area	Strongly Agree	Agree	Marginal	Disagree	Strongly Disagree	Score
Microbiology	10[a]	1	0	0	0	21[b]
Chemistry	5	5	1	0	0	15
Cell biology	10	1	0	0	0	21
Molecular biology	11	0	0	0	0	22
Food science	4	5	2	0	0	13
Chemical engineering	3	6	2	0	0	12
Industrial engineering	1	1	5	4	0	-1
Electronic engineering	1	2	4	3	1	-1
Genetics	8	3	0	0	0	19
Food processing	3	7	1	0	0	13
Biochemical engineering	5	5	1	0	0	15
Biochemistry	9	2	1	0	0	20
Mechanical engineering	1	2	4	3	1	-1

[a] Indicates the number of specialists who selected the category.

[b] Score: 2, strongly agree; 1, agree; 0, marginal; -1, disagree; -2, strongly disagree.

questionnaire.

After the results of the second questionnaire and panel discussion were sorted and analyzed, all the six newly added knowledge areas obtained scores above 0. Only two out of fifteen experts disagreed with including Zoology, Plant biology and Physiology on the list of biotechnology knowledge areas. The final version which reflects the consensus of the expert panel is shown in Table 2.

2. Subdivision Titles and Major Concepts

The preliminary understanding of the conceptual framework was derived from *Molecular Biotechnology* by Glick & Pasternak (1994) and *Molecular Biotechnology* by Primrose (1991). The sixteen subdivisions of *Nature of biotechnology, History of biotechnology, Basic knowledge of molecular biotechnology, Major techniques of molecular biotechnology, Manipulation of gene expression in prokaryotes, Manipulation of eukaryotic cells, Protein engineering, Microbial synthesis of commercial products, Molecular diagnostics, Vaccines and therapeutic agents, Bioremediation, Large-scale production of proteins from microorganisms, Transgenic animals, Gene therapy, Plant biotechnology and Social aspects of biotechnology* were listed on the first questionnaire. All sixteen subdivisions obtained a score above zero (Table 3). However, during the panel discussion, 10 out of 15 experts suggested integrating the major concepts of *Plant biotechnology* into other subdivisions, such as *Manipulation of eukaryotic cells*. Therefore, *Plant biotechnology* was excluded from the final version (Appendix).

The major concepts under each subdivision all obtained a positive score. However, several concepts did obtain a relatively low score (below 10). In addition, the following issues were subjected to intensive debate during the panel discussion:

(1) Should biotechnology be divided into classical biotechnology and modern biotechnology (or molecular biotechnology)? Eight out of fifteen experts agreed that there was a distinction between classical and modern biotechnology.

(2) Should "site-directed mutagenesis", "expression of recombinant genes", "polymerase chain reaction" and "transgenic animals" be included in *Basic knowledge of molecular biotechnology?* Thirteen out of fifteen experts finally agreed to consider these four concepts as "basic knowledge," instead of "basic techniques" of biotechnology.

(3) Nine out of fifteen experts regarded "major techniques of protein engineering" as *Major techniques of molecular biotechnology*. In addition, it was thought that "identification of recombinant genes" (i.e. Southern blotting, Northern blotting and Western blotting) should be included among basic techniques.

(4) Ten out of fifteen experts agreed that "integration of foreign DNA" need not be a major concept under the *Manipulation of gene expression in prokaryotes* subdivision.

(5) Eleven out of fifteen experts suggested merging *Saccharomyces* and *Pichia pastoris* system in the concept of "yeast expression system". In addition, it was felt that the concept of "plant cell expression system" should be added to *Manipulation of gene expression in eukaryotic cells* since the "plant biotechnology" subdivision had been deleted.

(6) Under the *Microbial synthesis of commercial products* subdivision, thirteen out of fifteen experts suggested merging "restriction endonuclease" in the major concept "protein pharmaceuticals".

(7) Both "small biological molecules" and "biopolymers" obtained relatively low scores (4 and 5, respectively) since five out of fifteen experts considered these concepts were not specific enough to make a judgment.

(8) The term "molecular diagnostics" could not cover all newly developed diagnostic systems. Therefore, the title of the subdivision was replaced by *Diagnostic products*.

(9) In light of written comments and conclusions of panel discussions, *Large-scale production of proteins from microorganisms* was replaced by *The major techniques of industrial microbiology*. The major concepts under this subdivision consisted of "downstream process-

Table 2. The Knowledge Areas of Biotechnology-Order of Significance

Order	Area	Order	Area
1	Molecular biology	9	Physiology
2	Microbiology	10	Chemistry
3	Cell biology	11	Biochemical engineering
4	Biochemistry	12	Food science
5	Genetics	13	Chemical engineering
6	Immunology	14	Food processing
7	Zoology	15	Animal breeding
8	Plant biology	16	Medical engineering

Note: The order for individual areas was based on their scores from the questionnaire.

Table 3. Degree of Consensus on the Subdivision and Major Concepts of Biotechnology

Subdivision Concepts	Strongly Agree	Agree	Marginal	Disagree	Strongly Disagree	Score
Nature of Biotechnology	0[a]	8	3	0	0	8[b]
Definition	2	8	1	0	0	12
Features of biotechnology	3	6	2	0	0	12
Social aspects of biotechnology	2	8	1	0	0	12
History of Biotechnology	1	7	2	1	0	8
Early development (B.C. 900 to A.D. 1800)	1	8	2	0	0	10
Zymotechnology (A.D. 1800 to 1900)	2	6	3	0	0	10
Organic compound production	2	7	1	1	0	10
Antibiotics production	2	7	1	1	0	10
Molecular biotechnology	4	6	1	0	0	14
Future development	2	8	0	1	0	11
Basic Knowledge of Molecular Biotechnology	3	8	0	0	0	14
Impacts of molecular biology	1	10	0	0	0	12
Basic knowledge	1	10	0	0	0	12
Major Techniques of Molecular Biotechnology	2	8	0	1	0	11
Synthesis of oligonucleotides	2	6	3	0	0	10
DNA sequencing	2	9	0	0	0	13
Polymerase chain reaction	1	8	0	2	0	8
Cell culture technique	3	8	0	0	0	14
Manipulation of Gene Expression in Prokaryotes	3	7	1	0	0	13
Prokaryotic cell gene structure and expression	3	7	1	0	0	13
Isolation of a functional promoter	1	8	2	0	0	10
Fusion proteins	2	7	2	0	0	11
Copy number	2	7	2	0	0	11
Protein synthesis in prokaryotic cells	2	8	1	0	0	12
Integration of foreign DNA	2	8	1	0	0	12
Pathways of protein secretion in prokaryotic cells	2	8	1	0	0	12
Manipulation of Eukaryotic Cells	2	8	1	0	0	12
Saccharomyces expression system	2	7	2	0	0	11
Pichia pastoris expression system	1	9	1	0	0	11
Insect cell expression system	1	6	3	1	0	7
Mammalial cell expression system	2	7	2	0	0	11
Protein Engineering	2	9	0	0	0	13
The purpose of protein engineering	2	9	0	0	0	13
Site-directed mutagenesis	1	10	0	0	0	12
Random mutagenesis	0	11	0	0	0	11
Major techniques of protein engineering	2	8	0	1	0	11
Microbial Synthesis of Commercial Products	2	7	0	2	0	9
Protein pharmaceuticals	1	9	1	0	0	11
Restriction endonuclease	2	7	1	1	0	10
Small biological molecules	1	4	4	2	0	4
Biopolymers	1	4	5	1	0	5
Molecular Diagnostics	3	7	0	1	0	12
Immunological diagnostic products	2	7	1	1	0	10
DNA diagnostic system	2	7	2	0	0	11
Vaccines and Therapeutic Agents	0	11	0	0	0	11
History of vaccines	2	7	-2	0	0	11
Subunit vaccines	1	6	3	1	1	5
Attenuated vaccines	1	5	4	1	1	4
Monoclonal antibodies as therapeutic agents	1	5	4	1	1	4

(to be continued)

Table 3. (continued)

Subdivision Concepts	Strongly Agree	Agree	Marginal	Disagree	Strongly Disagree	Score
Biodegradation	3	6	1	1	0	11
Biodegradation of toxic waste	1	6	2	2	0	6
Genetic engineering of biodegradative pathways	1	6	4	0	0	8
Utilization of starch	1	8	3	0	0	10
Utilization of cellulose	1	8	2	0	0	10
Large-scale Production of Proteins from Microorganisms	1	9	1	0	0	11
Characteristics of microbial growth	1	8	1	1	0	9
Large-scale cultivation	1	8	2	0	0	10
Downstream processing	1	9	1	0	0	11
Immobilization	2	8	1	0	0	12
Transgenic Animals	1	9	0	1	0	10
Transgenic mice: methodology	1	9	0	1	0	10
Transgenic mice: applications	1	8	2	0	0	10
Transgenic strains of livestock	1	8	0	2	0	8
Transgenic birds	1	10	0	0	0	12
Transgenic fish	1	8	2	0	0	10
Gene Therapy	2	7	1	1	0	10
Target diseases for human gene therapy	1	7	3	0	0	9
Gene mapping	1	6	4	0	0	8
Techniques of somatic cell gene therapy	1	7	3	0	0	9
Plant Biotechnology	2	6	3	0	0	10
Breeding by recombinant DNA techniques	1	7	3	0	0	9
Application of plant biotechnology	1	8	2	0	0	10
Social Aspects of Biotechnology	3	8	0	0	0	14
Patent applications	1	7	1	2	0	7
Regulating the usage of biotechnology	2	7	2	0	0	11
DNA fingerprints	1	9	1	0	0	11
Social aspects of gene therapy	2	9	0	0	0	13
Prospects of biotechnology education	1	8	2	0	0	10

[a] Indicates the number of specialists who selected the category

[b] Score: 2, strongly agree; 1, agree; 0, marginal; -1, disagree; -2, strongly disagree.

ing", "characteristics of microbial growth", "large-scale cultivation", "product purification and waste disposal" and "immobilization techniques".

(10) Major changes were made to the content of the subdivision *Social aspects of biotechnology* after the panel discussion. Thirteen out of fifteen experts suggested that "DNA fingerprint", "regulating the usage of biotechnology" and "social aspects of gene therapy" should be merged in the single concept "the impact of biotechnology on the society". In addition, it was suggested that the major concept "restrictions on biotechnology research and development", which covered regulations and guideline concerning R&D, should be added under this subdivision.

The final version of a taxonomic structure for the field of biotechnology is shown in Appendix.

IV. Discussion

The potential of biotechnology has been realized by most educators in our country. It is predicted that individuals who will be or are in biotechnology industries will be requested to have specific education and training in biotechnology.

This study identified the basic knowledge areas of biotechnology and classified the content of biotechnology. Table 2 presents the final version of the knowledge areas. Individuals in the field of technology education or biological science education may have different viewpoints regarding how to use this list for curriculum development. Those who are developing a curriculum for technology education may emphasize chemical engineering, food processing, biochemical engineering, animal breeding and medical engineering. For those who are developing a curriculum for biological science education, microbiology, chemistry, cell biology, molecular biology, zoology, plant biology, physiology, genetics, biochemistry and immunology would be major disciplines of interest. Glick & Pasternak (1994), for example, in their book "*Molecular Biotechnology: Principles and Applications of Recombinant DNA*" suggested that many scientific disciplines contribute to molecular biotechnology, including molecular biology, microbiology, biochemistry, genetics, chemical engineering and cell biology. Those disciplines emphasize theory, discovery and experimentation. In this study, no technology education or biotechnology industry experts were invited to join the expert panel. Therefore, the outcome inevitably emphasized basic knowledge and skills needed for research and development. Further investigation will be necessary to define the core competence for students who seek a career in the biotechnology industry, and the emphasis should be on designing, creating, applying and ultimately leading to a commercial product.

A complete taxonomic structure for biotechnology is listed in Appendix. A completed taxonomy should be very useful in developing a blueprint for curriculum development. Although the contents of the list ran into the same problem as the "knowledge areas," which heavily emphasized biological science education, an effort was made to include several subdivisions that were closely related to technological education, such as "*Major techniques of industrial microbiology*" and "*Microbial synthesis of commercial products*". De Landsheere (1991) addressed the fact that the content validity of a taxonomy will not be considered perfect by any author, but it allows nearly all the cognitive objectives of education to be classified. In addition, the subcategorization used in a taxonomy is not always based on the same classification principle. It should be based on whether the taxonomy is to be used for comprehension or evaluation. The taxonomy presented here was not intended to make a judgment about the value of any specific theory, idea, process or methodology. Instead, it was a comprehensive taxonomy. Therefore, the addition of several subdivisions relating to technological education did not go against our principles.

When developing a particular curriculum, the content of the taxonomy often only presents a theme, and there is no indication given about what instructional objectives should be developed under the theme. Based on the taxonomic structure, instructional objectives developed for teaching biotechnology courses in technology education and biological science programs would differ in approach, yet remain centered around a consistent content (Wells, 1994). Therefore, an ideal model curriculum should be tailored to meet the needs of various applications, and would require careful scrutiny by both industry and academic institutions (Rinard, 1986).

A curriculum should be integrated instead of simply adding new materials into a preexisting course as an appendage. Therefore, a conceptual framework for biotechnology will be essential for developing the curriculum (Hudson, 1988). DeVore (1966) indicated that a complete taxonomic structure would eliminate confusion and simplify the task of curriculum planning by providing a perspective of the relationships between the elements and the structure. It would order knowledge areas into specific categories, and identify the difficulty level of content areas in order to establish instructional sequences at different learning levels. The taxonomic structure shown in Appendix suggested a hierarchical relationship between a basic knowledge level and a higher technical level. Therefore, it allows the principles of individual techniques to be grouped into the subdivision "*Basic knowledge of molecular biotechnology*". The principle of creating a transgenic animal, for example, was classified into the third level of "*Basic knowledge of molecular biotechnology*" instead of being classified into the subdivision "*Transgenic animals*". The technical aspects of transgenic animals, on the other hand, remained in the subdivision "*Transgenic animal*". In other words, the order of learning biotechnology suggested by this taxonomic structure was to understand the basic principle of individual techniques first and then to introduce specific applications in individual fields.

In conclusion, an ideal curriculum for biotechnology programs should meet the objectives of the educational program and cover both principles and applications in a logical sequence. In addition, the students entering the program should have background knowledge covering disciplines including molecular biology, cell biology, genetics, biochemistry and microbiology.

Acknowledgment

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Appendix

Taxonomic Structure of Biotechnology

1. Nature of biotechnology
  1.1 Definition of biotechnology
  1.2 Nature of biotechnology
  1.3 Social aspects of biotechnology

2. History of biotechnology
  2.1 Prehistoric development (B.C.9000-A.D.1800)
  2.2 Zymotechnology (A.D.1800-A.D.1900)
  2.3 Industrial microbiology (A.D.1900-A.D.1960)
    2.3.1 Production of organic compounds
    2.3.2 Production of antibiotics
    2.3.3 Production of special chemicals
  2.4 Molecular biotechnology (A.D.1960 to present)
    2.4.1 Development of molecular biology
    2.4.2 Genetic engineering
    2.4.3 Transgenic animals
    2.4.4 Gene therapy

3. Basic knowledge of molecular biotechnology
  3.1 Impacts of molecular biology
  3.2 Basic knowledge
    3.2.1 DNA
    3.2.2 Restriction endonuclease
    3.2.3 Plasmids
    3.2.4 Gene library
    3.2.5 Expression of eukaryotic genes
    3.2.6 Vectors
    3.2.7 Transformation of prokaryotic cells
    3.2.8 Site-directed mutagenesis
    3.2.9 Expression of recombinant genes
    3.2.10 Polymerase chain reaction
    3.2.11 Transgenic animals

4. Major techniques of molecular biotechnology
  4.1 Synthesis of oligonucleotides
  4.2 DNA sequencing
  4.3 Identification of specific genes
    4.3.1 Southern blotting
    4.3.2 Northern blotting
    4.3.3 Western blotting
  4.4 Cell culture techniques
    4.4.1 Microbial cell culture
    4.4.2 Animal cell culture
    4.4.3 Plant cell culture
  4.5 Major techniques of protein engineering

5. Manipulation of gene expression in prokaryotes
  5.1 Structure and expression of prokaryotic cell genes
  5.2 Promoters
    5.2.1 Isolation of a functional promoter
    5.2.2 Criteria for a good promoter
  5.3 Fusion proteins
  5.4 Control of the gene copy number
  5.5 Protein synthesis in prokaryotic cells
  5.6 Control of protein secretion from prokaryotic cells

6. Manipulation of gene expression in eukaryotes
  6.1 Yeast gene expression system
    6.1.1 *Saccharomyces cerevisiae*
    6.1.2 *Pichia pastoris*
  6.2 Insect cell gene expression system
    6.2.1 Baculoviruses
  6.3 Mammalial cell gene expression system
    6.3.1 Vectors for mammalian cells
    6.3.2 Applications
  6.4 Plant cell gene expression system

7. Protein engineering
  7.1 The specific aims of protein engineering
  7.2 Site-directed (oligonucleotide-directed) mutagenesis
    7.2.1 M13 system
    7.2.2 PCR-amplified system
  7.3 Random mutagenesis

8. Microbial synthesis of commercial products
  8.1 Production of protein pharmaceuticals using recombinant DNA techniques
  8.2 Production of small biological molecules
    8.2.1 Antibiotics
    8.2.2 Vitamins
    8.2.3 Starch-derived products
  8.3 Production of biopolymers
    8.3.1 Principle and advantage of using microorganisms to synthesize biopolymers
    8.3.2 Polymers produced by microorganisms

9. Diagnostic products
  9.1 Immunological diagnostic systems
    9.1.1 Applications of monoclonal antibodies
    9.1.2 Antigen diagnostic systems
    9.1.3 Major techniques in immunological diagnostic procedures.
  9.2 DNA diagnostic system
    9.2.1 DNA hyhridization techniques
    9.2.2 Non-radioactive DNA diagnostic procedures
    9.2.3 Application of DNA diagnostic systems

10. Vaccines and therapeutic antibodies
  - 10.1 History of vaccines
  - 10.2 Attenuated vaccines
  - 10.3 Subunits vaccines
  - 10.4 Monoclonal antibodies as therapeutic agents
  - 10.5 Application of genetic engineering to the production of vaccines and antibodies

11. Bioremediation
  - 11.1 Biodegradation of organic wastes
  - 11.2 Manipulation of degradative pathways using recombinant DNA techniques
  - 11.3 Biodegradation of cellulose

12. Major techniques of industrial microbiology
  - 12.1 Downstream processes
  - 12.2 Characterization of microbial growth
    - 12.2.1 Factors that regulate microbial growth
    - 12.2.2 Measurement of microbial growth
    - 12.2.3 The principle of continuous culture
  - 12.3 Large-scale cultivation
    - 12.3.1 Parameters of large-scale culture
    - 12.3.2 Basic design of a bioreactor
    - 12.3.3 Control system of a bioreactor
  - 12.4 Purification and waste disposal
  - 12.5 Immobilization
    - 12.5.1 Advantages of immobilization
    - 12.5.2 Techniques of immobilization
    - 12.5.3 Criteria for the choosing types of immobilization

13. Transgenic animals
  - 13.1 Methodology for generating transgenic mice
    - 13.1.1 Procedures for generating transgenic mice
    - 13.1.2 Characterization of transgenic mice
  - 13.2 Applications of transgenic mice
    - 13.2.1 Gene repair
    - 13.2.2 Gene knockout
  - 13.3 Transgenic cattle
  - 13.4 Transgenic pigs
  - 13.5 Transgenic birds
  - 13.6 Transgenic fish

14. Gene therapy
  - 14.1 Genetic disorders
  - 14.2 Establishment of the human genome map
    - 14.2.1 Genetic linkage
    - 14.2.2 Restriction fragment length polymorphism (RFLP)
    - 14.2.3 Positional cloning
  - 14.3 Somatic cell gene therapy
    - 14.3.1 Ex vivo gene therapy
    - 14.3.2 In vivo gene therapy
    - 14.3.3 Antisense RNA gene therapy

15. Social aspects of biotechnology
  - 15.1 Patent applications
  - 15.2 Impact of biotechnology on society
    - 15.2.1 Regulating the usage of biotechnology
    - 15.2.2 DNA fingerprints
    - 15.2.3 Social Impact of gene therapy
  - 15.3 Restrictions on biotechnology research and development
  - 15.4 Prospects of biotechnology education

Taxonomy of Biotechnology

生物技術科學課程內容分類架構之專家評析

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摘　　要

生物技術科學爲我國科技發展的八大重點學門之一，本研究即在探討生物技術科學之範圍與內容，並發展出內容分類架構。研究方法採用修改過之「大慧術」（Delphi technique），過程包括「文獻探討」、「擬定問卷」、「選定專家」、「寄發及回收問卷」、「初步修正」、「寄回修正問卷」、「專家訪談」、「第二次修正」、「定稿」等程序，在生物技術科學的範圍與內容上，獲得專家廣泛意見及共識。參與問卷填答之專家有11位，參與訪談及座談之專家，連研究者本身共16位，結論爲：⑴ 生物技術科學涵蓋16個領域，包括微生物學、化學、細胞生物學、分子生物學、食品科學、化學工程學、動物學、植物學、生理學、遺傳學、食品技術工程學、生化工程學、生物化學、免疫學、動物培養學及醫學工程學；⑵ 生物技術科學應包涵生物技術科學的本質、生物技術科學的演進、分子生物技術科學的基本知識、分子生物技術科學的主要技術、操縱原核細胞基因之表現、真核細胞的表現系統、蛋白質工程技術、診斷試劑、疫苗及治療製劑、生物性分解作用、工業微生物產品之生產技術、基因轉殖動物、基因治療及生物技術科學之社會觀等15個主概念，每一主概念及次概念則以生物分類法組成分類架構。本分類架構將能對爾後生物技術科學教材之編寫、生物技術科學課程之設計、生物技術工業投資策略之擬定及生物技術研發方向之評估有所助益。

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A Study of the Concept "Living Organism" and Living Organism Classification in Aboriginal Children

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ABSTRACT

This study investigated the understanding and application of the concept "living organism" in aboriginal children. Thirty-six 2nd, 4th,and 6th graders were selected from an aboriginal elementary school in Hualien. A structured, clinical interview with two different approaches was designed to assess the subjects' ability to classify familiar and unfamiliar objects according to life status. The results indicated four forms of classification: (1) living; (2) non-living; (3) animal; (4) botanical. Children in all grades used at least two of them. Movement and growth were the most commonly given attributes of life and "living organisms". Young children relied relatively heavily on attributes true for animals but not for plants, whereas older children did the reverse. It was also found that children's concepts of "living organisms" and "living things" were different. They used individual experience more to attribute life and less to classify as "living organisms". "Human" was seen as living but not considered a "living organism". The biological subsets of plants (eg. trees, grasses, flowers) and animals(eg. birds, fish, tigers) were classified as comparable to the set "plant" and "animal", not as subsets of them. Sophistication of conceptual development was not found to improve with age. Finally, possible sources of misconception and the relationship between life attribution, cognitive development and linguistic factors were discussed.

Key Words: aborigines, living organism, life concepts, classification

I. Introduction

1. Research Background

Numerous research on the concept of life has been carried out in this country and worldwide. This has mostly centered on animism or children's views of life attributes (Russell & Dennis, 1939; Russell, 1940; Huang & Lee, 1945; O-saki & Samiroden, 1990; Su, 1968; Wang, 1993). Though there has been some research done on the subject of the class concept of "living organism" (Ryman, 1974a, 1974b), in English this term is closed related to the terms "living", "alive" or "life" which makes the focus of this research the realm of "life". The Chinese term for "living organism" (Sheng-Wu) does not have such close association with the term for "living" (Hwo). "Living organism" (Sheng-Wu) is a little closer to "life" (Ming or Shen-Ming) (which like the term for "living"(Hwo) is in colloquial use), but is a biological term used mainly in the classroom. Do aboriginal children also differentiate these terms? This is what we wanted to find out. Moreover, although the aboriginal children receive a standard Chinese education, they live mainly in a natural environment with wildlife as one of their food sources. It is conceivable, therefore, that their experience and knowledge of living organisms should be different from that of non-aboriginal children. It follows that it would be beneficial for future elementary school course design and teaching to investigate aboriginal children's ability to recognize and classify living organisms.

2. Purpose of the Research

The purpose of our research is to:

(1) Understand the differences, if any, in aboriginal children's conceptual comprehension of "living", "life" and "living organism".
(2) Understand aboriginal children's definition of "living organism".
(3) Understand how aboriginal children classify the

familiar living and non-living objects in their surroundings.

(4) Study how aboriginal children decide whether an unfamiliar living thing is a living organism. How do they apply their concepts? What is significant in their recognition of life attributes?

3. Limitations of the Research

Our criterion of measurement was the children's classifying behavior. That is, we studied the children's cognitive perspectives based on the generalizations and discriminations of their classification scheme. Under these limitations, the scope of our research was as follows:

(1) Our study dealt only with the familiarity of concepts, not how they are formed.

(2) "Aboriginal children" was limited to children of the Taya tribe only. They did not include children of other aboriginal tribes.

(3) The content of the children's concept of living organisms was limited to what they remembered during interviews, which may not be representative of their full knowledge.

Based on the purposes of this study, we chose Mandarin as the language of interview.

II. Methods

1. Subject

The subjects of this study were 36 children in the 2nd, 4th and 6th grades of a Taya elementary school. The school is situated in a traditional Taya village in a mountainous region of Hualien. As in most aboriginal schools of eastern Taiwan, there is only one classroom for each grade with 20 or fewer students in it. Selection of students was done randomly by the researcher. Three groups of 12 students each with an equal number of boys and girls were selected from the 2nd, 4th and 6th grade classrooms.

2. Instruments

The study collected data through clinical interviews divided into two phases. In the first phase the children's understanding of "living things"(Hwo Wu), "things of life"(Shen-Ming Wu) and "living organism" (Sheng-Wu), and their classification of living organisms was investigated. The procedure was as follows:

Their scope of understanding of the concepts "living","life" and "living organism"

- "Name five living things (Hwo-Wu)
- Name five things of life (Sheng-Ming Wu)
- Name five living organisms (Sheng-Wu)"

↓

Their definition of "living organism"

- "What is a living organism(Sheng-Wu)? Tell what you mean."

↓

Their classification of "living organisms"

- Presented with 24 cards depicting instances(plants and animals) and non-instances(inanimate objects, man-made objects and natural things) children were asked: "Is this a living organism (Sheng-Wu)? Why do you think so? Give as many reasons as you can."

In second phase, five living objects never taught to the children were used to examine their concept of "living organism". The children were asked three main questions: "Is this a living organism(Sheng-Wu)?"; "Is this a living thing(Hwo-Wu)?" ; "Why do you think so?"

Based on Berzonsky's and Tamir's studies (Berzonsky, Ondarado, & Williams, 1977; Tamir, Gal-Choppin, & Nuuinovitz, 1981), the illustrations on the cards depicted the following: tiger, bird, fish, girl, snail, snake, tree, grass, rose, vegetable, peach, mushroom, chair, car, ship, bicycle, clock, television, cloud, fire, mountain, river, lightning and sun. Objects of life taken from around the children's own environment were: crustaceous lichen, liverworts, cushiony mosses, filamentous green algae and slugs.

The testing instrument was submitted to a panel of evaluators made up of two university biology teachers, a science educator, an elementary school teacher and graduate student, and an aboriginal school teacher. Each item was reviewed for consistency with the classification task, and for clarity of expression. The instrument was finalized through field testing on a group of elementary school children.

3. Analysis

Children were interviewed at school in a room near their home classroom. Each interview lasted 20-25 minutes and was videotaped for later analysis. The following scoring procedures were employed: Examples elicited for each concept were recorded. If a child provided more than 5, only the first 5 examples were scored. All traits mentioned in their working definitions were listed and tabulated. The justifications for their classification were divided into the following categories:

(1) Attributes of living organisms: (i) growth, (ii) breathing, (iii) reproduction, (iv) living, (v) life, (vi) death.
(2) Attributes of plants: (i) Photosynthesis, (ii) absorbing water, (iii) growing in soil, (iv) having stems, flowers, seeds, (v) living in a specific location, (vi) being green.
(3) Attributes of animals: (i) movement, (ii) eating, (iii) excretion, (iv) making sound, (v) attacking, (vi) having specific behavior, (vii) having a specific location, (viii) having a heart, (ix) being an animal.
(4) Attributes of non-living organisms: (i) edibility, (ii) absorbing nutrients(misused in plant), (iii) having the pith of a tree, (iv) usability, (v) showing intuitive responses.

Based on the above categories, four types of thinking were identified in aboriginal children.

III. Results

1. Aboriginal Children's Understanding of the Concept of "Living Organism".

A. Examples of Living Organisms

The average number and scope of examples of "living things", "things of life" and "living organisms" given by the children are shown as follows (Table 1):

The aboriginal children had a different understanding of "living things", "things of life" and "living organisms". Their performance was best with "living things", next with "things of life", and worst with "living organisms". "Living things" and "things of life", though not different in colloquial Chinese usage, obviously held a different degree of familiarity for aboriginal children. As for "living organism", most children did not know what it meant. This indicated that concepts from classroom teaching were not being brought home to daily life. Aboriginal children still had a problem with understanding the term "living organism".

Table 1. Average and Range of Number of Examples for "Living Things", "Things of Life" and "Living Organism"

	2nd grade (N=12)		4th grade (N=12)		6th grade (N=12)	
	average	range	average	range	average	range
*living things	1.92	0~5	4.25	0~5	3.25	0~5
*things of life	1.25	0~5	2.58	0~5	2.92	1~5
*living organisms	0.42	0~5	0.58	0~5	1.83	0~5

Note: Each categery contains 5 examples.

B. Content of Living Organisms

An analysis and categorization of examples of "living things", "things of life", and "living organisms" given by the aboriginal children yielded the following:

(1) The children's knowledge was richest with respect to "living things", with a total of 36 animals, plants, and *prokaryotes*. Next was "things of life" with a total of 34 plants, animals, and living organisms (Sheng-Wu). "Living organisms" had only 24 animals and plants given. Of all the examples, animals comprised the greatest number. Next was plants. Living organisms (Sheng-Wu) and *prokaryotes* had the fewest. "Living organism (Sheng-Wu)" and bacteria were used by only one child each.
(2) The Children's examples of "living things" and "things of life" were mainly animals. For "living organism", more total animals were given, but more children used plants as examples, (Table 2). This indicated that most children thought of animals as "living things" or "things of life", and plants as "living organisms" .
(3) When giving animals as "living things" and "things of life", the most common examples were "human" and "animal". The next were zoo animals such as "lion" and "tiger". Next came animals that are found in the children's environment, such as "bird", "cat" and "dog". In the children's thinking, the label "animal" is a class on the same level as human, lion, tiger, bird, cat and dog.
(4) The children gave a very limited number of plants as examples. Most used "tree", "flower", "grass", or "plant". Very few used specific plant names. This showed that in children's thinking the label "plant" is a class on the same level as tree, flower and grass.
(5) Generally speaking, the content of "living things" and "things of life" increased in complexity in the case more mature children. However, the mistake of classifying plant items and animal items as comparable to the sets "plant" and "animal" themselves also increased (seven 6th graders, five 4th graders and one 2nd grader made this mistake).

C. Definition of Living Organisms

When asked what they meant by the term "living

Table 2. Most Frequently Named "Living Things", "Things of Life" and "Living Organism"

	Provided as:		
	living things (N=36)	things of life (N=36)	living organisms (N=36)
Animals:			
1. animal	13	10	0
2. human	8	13	1
3. tiger	8	5	1
4. bird	6	3	1
5. elephant	5	1	0
6. lion	5	3	2
7. dog	5	3	0
8. monkey	4	0	1
9. rabbit	4	0	0
10. cat	4	3	0
11. snake	4	1	0
12. goat	3	1	1
13. fish	3	1	2
Plants:			
1. tree	9	11	5
2. flower	5	4	4
3. plant	3	2	2
4. grass	1	2	0

organism" (Table 3), none of the 2nd and 4th graders could give a definition. Among the 6th graders, only one child could use the biological definition "growth" to describe living organisms. One child used an attribute of plants ("breathes in carbon dioxide, breathes out oxygen") and an attribute of animals ("can move") to describe living organisms. Another child used the colloquial term "alive" to describe living organisms.

2. Aboriginal Children's Classification of Living Organisms

Table 3. Number of Definitions of Living Organisms and Living Organism Attributes

	2nd grade (N=12)	4th grade (N=12)	6th grade (N=12)	total (N=36)
No. of definitions of living organisms	0	0	3	3
Attributes:				
1. living			1	1
2. moving			1	1
3. breath in carbon dioxyde breath out oxygen			1	1
4. possess life			1	1
5. will grow			1	1

A. Classification of Living Organisms

As seen in Table 4 and Fig. 1, most children could identify over 4 animals or plants as living organisms. In general, the more senior the grade, the better the performance. But the 4th graders did not perform significantly better than the 2nd graders. Comparing the performance in each grade, we found that 2nd graders tended to classify animals as living organisms but not plants. The 6th graders tended to classify plants as living organisms but not animals.

For each of the plant items, Fig. 2 shows that:

(1) The percentage of children who classified grass, peach and mushroom as living organisms increased with age.

(2) The 4th graders did no better than the 2nd graders of classifying tree, rose and vegetable. In particular for rose, only 67% of the 4th graders classified it as a "living organism", which was less than for the 2nd graders (75%).

(3) In the classification of plants, the 2nd and 4th graders showed a wide discrepancy, with correct responses ranging from 50% to 75%. The 6th graders were more consistent, with correct responses ranging from 83% to 100%. This indicated that the older children were more positive about plants being living organisms.

(4) Mushrooms are a member of the fungi and most children, regardless of their grade, could identify them as a living organism. Yet the vegetables we eat on a daily basis had the lowest percentage of being identified correctly as a living organism by the 2nd and 4th graders (about 50%).

For the animal items, the children's performance did not necessarily improve with age. Fig. 3 demonstrates that:

(1) On the whole, 2nd graders had the highest percentage of classifying animals as living

Table 4. Average and Range of Number of Correct Living Organism Classifications

	Plant[a]		animal	
	average	range	average	range
2nd grade (N=12)	3.83	0~6	4.75	1~6
4th grade (N=12)	4.00	0~6	4.17	0~6
6th grade (N=12)	5.58	3~6	5.08	0~6

[a] involve mushroom

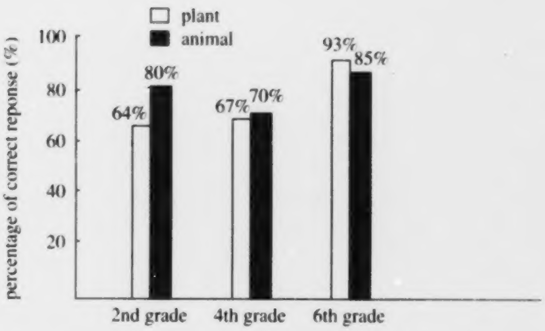


Fig. 1. Percentage of correct response for "animal and plant items" by aboriginal children of each grade.

organisms. Next were the 6th graders. The worst were the 4th graders.

(2) In the classification of living organisms, "human"(girl) was regarded differently from other animals. The lowest percentage of children in each grade classified human as a living organism,barely 50%.

(3) For non-human animals, the 2nd and 4th graders showed a large discrepancy in their viewpoint. The percentages for snake and snail being classified as living organisms were lower than that for tiger, fish and bird. The 6th graders, however, were more consistent. Snake, snail, tiger, fish and bird were classified as living organisms by about the same percentage of children.

B. Attributes of Living Organisms

i. Living Organism Attributes of Plants

After children classified tree, grass, rose, vegetable, peach and mushroom as living organisms, they were asked to justify their choice. Table 5 shows the results as follows:

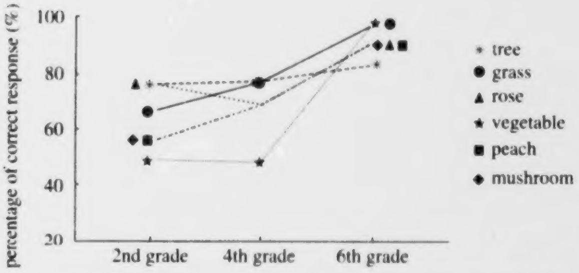


Fig. 2. Distribution of correct response for "plant items" by aborigial children of each grade.

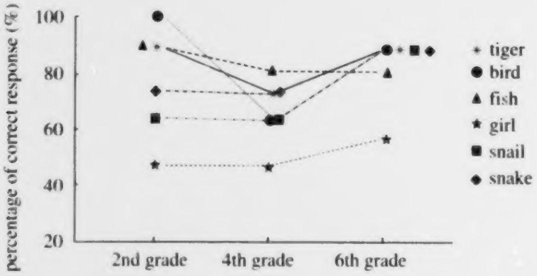


Fig. 3. Distribution of correct response for "animal items" by aboriginal children of each grade.

(1) There were 3 types of reasoning children used when classifying plants as living organisms. One was the presence of living organism attributes; one was the presence of plant attributes and one was the presence of non-living organism attributes. As for frequency of use, the greatest number of children used plant attributes, followed by living organism attributes. Very few used non-living organism attributes.

(2) Among living organism attributes, "growth", "breathing" and "reproduction" are scientifically acceptable, while "life" and "death" are colloquial terms, not mentioned in biology textbooks. "Growth" was the attribute most often used by all children in classifying plants as living organisms. "Breathing" was used mostly by 6th graders. "Reproduction" was not mentioned much. The colloquial terms "life" and "death" were not used much by the 2nd and 4th graders, but were used quite often (almost 50%) by the 6th graders.

(3) Plant attributes are not the basis for classifying living organisms. However, most children used them, and moreover the use increased with age. Attributes used by 6th graders included "photosynthesis", "absorbing water", "growing in soil", and "specific location". These attributes were rarely given by the younger children.

(4) The non-living organism attributes were used mostly by the 6th graders. The terms they used most often were "edibility" and "absorbing nutrients". The former came from the children's personal life experience. The latter might have come from a misunderstanding of what they had been taught. This showed that though children could classify living organisms correctly, they might not be using the correct attributes.

Table 5. Analysis of Attributes Used in Classifying Plants as Living Organisms by Each Grade of Aboriginal Children

Attribute	2nd grade (N=12)	4th grade (N=12)	6th grade (N=12)	total (N=36)
Attributes of living organisms:				
1. growth	5	4	8	17
2. breathing	1	0	3	4
3. reproduction	1	1	0	2
4. life	0	2	3	5
5. death	1	0	5	6
Attributes of plants:				
1. photosynthesis	0	0	5	5
2. absorbing water	0	3	6	9
3. grows in soil	1	3	6	10
4. has stems, leaves, flowers, seeds	1	1	3	5
5. lives in specific location	0	4	6	10
6. green	0	0	1	1
Attributes of non-living organisms:				
1. edibility	3	3	3	9
2. absorbing nutrients[a]	0	1	3	4
3. has pith of tree	0	1	0	1
4. usability	0	0	2	2
5. intuitive responses	1	1	1	3

[a] Misused criterion

ii. Living Organism Attributes of Animals

Table 6 shows the children's use of attributes in classifying animals as living organisms. It shows that:

(1) Children used three types of attributes to decide if animals were living organisms: living organism attributes, animal attributes, and non-living organism attributes. The most frequently used were the animal attributes. Next were the living organism attributes. The least used were the non-living organism attributes.

(2) Among the living organism attributes, only "growth", "breathing", and "reproduction" are criteria used by biologists . Althought the rest- "living", "life" and "death"- are colloquial terms, the children used them more frequently. This indicates that even if viability is not used by biologists, children tend to mostly rely on it to classify animals as living organisms.

(3) Regardless of grade, children used animal attributes with the highest frequency, indicating that most children use them to classify living organisms. Among animal attributes, "movement" was the most frequently given, (over half of each grade used it), followed by "attacking", "eating", "making sound", and "specific behavior". This shows that the children rely on an animal's behavior to decide if it is a living organism. One thing worth mentioning is that some children related animals to their habitats, thinking that living organisms live in a "specific location". This attribute is very similar to that of plants mentioned above.

(4) Non-living organism attributes were used very rarely. The only two such attributes were "usability" and "edibility". This was similar to the usage for plant items, except that the percentage was far lower.

C. Misclassification of Living Organisms

Figures 1-3 also show these facts:

(1) The 2nd and 4th graders had a similar error rate, far higher than that of the 6th graders.

(2) The 2nd and 4th graders made more mistakes on the animal and plant items. Except on "girl," the 6th graders made very few misclassifications.

The children's reasons for misclassification of animal items result from two different types of misconception (Table 7): (1) Animals are living organisms but humans are not animals, so humans are not living organisms. This is why children did not think of "girl" as a living organism. (2) Animals are not living organisms, and only plants are. Thus animals or things with animal attributes are not living organisms. For plants there were also two types of misconceptions: (1) Only animals are living organisms. Plants do not have animal characteristics and

Table 6. Analysis of Attributes Used in Classifying Animals as Living Organisms by Each Grade of Aboriginal Children

Attribute	2nd grade (N=12)	4th grade (N=12)	6th grade (N=12)	total (N=36)
Attributes of living organisms:				
1. growth	4	1	3	8
2. breathing	0	0	2	2
3. reproduction	1	1	1	3
4. living	1	1	2	4
5. life	0	4	4	8
6. death	1	1	3	5
Attributes of plants:				
1.movement	10	6	9	25
2. eating	2	2	7	11
3. excretion	0	0	1	1
4. making sound	1	2	4	7
5. attacking	6	3	4	13
6. specific behavior	0	0	6	6
7. specific location	0	3	3	6
8. has heart	0	1	0	1
9. an animal	0	1	2	3
Attributes of non-living organisms:				
1. usability	1	0	0	1
2. edibility	1	1	1	3

[a] Misused criterion

Table 7. Number of Children by Grade Citing Reasons Why Animals and Plants Are Not Living Organisms

Reasons for not being a living organism	grade			
	2nd (N=12)	4th (N=12)	6th (N=12)	total (N=36)
Animal:				
1. is human not animal	3	3	3	9
2. is a snail	1	0	0	1
3. bites people	1	2	0	3
4. eats animals	1	1	0	2
5. clings on people	1	0	0	1
6. eats	0	1	0	1
7. comes up from water	0	1	0	1
8. is an animal	0	2	1	3
9. is not a plant	0	0	1	1
10. is not a tree	0	1	0	1
11. does not have stems	0	1	0	1
Plant:				
1. does not move	3	3	0	6
2. eten by people	2	3	1	6
3. planted by people	0	1	0	1
4. can be crushed	1	0	0	1
5. will wither	1	0	0	1
6. is a vegetable	1	0	0	1
7. is not an animal	0	1	0	1
8. does not grow	1	0	0	1
9. has no life	0	1	0	1
10. has ants on it	1	0	0	1

therefore are not living organisms. (2) Plants do not have life characteristics and therefore are not living organisms.

3. Aboriginal Children's Classificatory Thinking Towards Living Organisms

Children's reasons for classifying animals or plants as living organisms reflect 4 types of thinking:

(1) "Living organism" type: classification was based on the presence of viability or biological attributes.

(2) "Animal" type: classification was based on whether it was a kind of animal or if it had animal attributes.

(3) "Plant" type: classification was based on whether it was a kind of plant, or if it had plant attributes.

(4) "Non-living organism" type: classification was based on non-living, non-biological attributes, or attributes that were unrelated to animals or plants.

Figure 4 presents the percentages of the above four types of thinking by grade level. It shows that:

(1) The living organism type of thinking increased with grade level.

(2) The animal type of thinking was most common among all grades, especially among 2nd graders. All children had a tendency toward using animal class and attributes to classify living organisms.

(3) The plant type of thinking was least common among the 2nd and 4th graders, only 17% and 25% respectively, but reached 92% for the 6th graders.

(4) The non-living organism type of thinking was least common among the 6th graders, only 17%, but 33% among the lower graders.

(5) The preferred types of thinking tendency for each grade were as follows: (i) The 2nd graders tended toward the animal type, with living organism and non-living organism types next. The plant type was the least common. (ii) The 4th graders did not show a strong tendency toward any one type, but living organism and animal types were used slightly more than plant and non-living organism. (iii) The 6th graders used plant and animal types the most with the living organism type next and the non-living organism type the least common.

To understand the patterns of thinking the children used to classify plants and animals, combinations of the above four types were analyzed. The results are shown in Table 8 and summarized as follow:

(1) Not many children used a single type of thinking. Most used a combination of two or more types.

(2) Of those who used a single type of thinking, the living organism type was the most common, appearing among roughly 1/4 of the 4th graders. Next was the animal type, appearing among roughly 1/6 of the 2nd graders. Only a few used of the non-living organism type exclusively. These were among the 4th and 6th graders. There was no instance of plant type thinking being exclusively used in any grade.

(3) Most children used a combination of types of thinking. (i) The 2nd graders tended to use "living organism type + animal type" and "animal type + non -living organism type". (ii) The

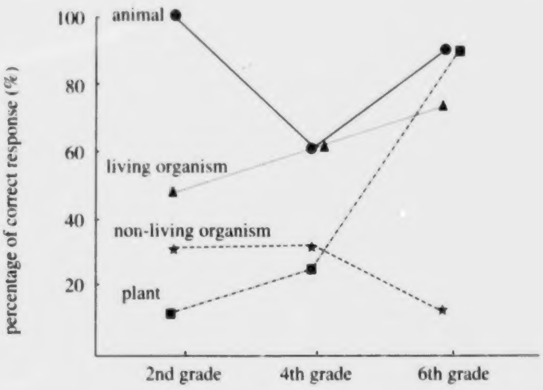


Fig. 4. Distribution of the four types of classification thinking by aboriginal children of each grade.

Table 8. Living Organism Thinking Patterns by Aboriginal Children of Each Grade

Patterns of thinking	grade			
	2nd (N=12)	4th (N=12)	6th (N=12)	total (N=36)
I	0	3	0	3
II	2	0	0	2
IV	0	1	1	2
I + II	4	3	0	7
II + III	0	2	2	4
II + IV	3	1	0	4
III + IV	0	1	0	1
I + II + III	1	0	8	9
I + II + IV	1	1	0	2
II + III + IV	1	0	0	1
I + II + III + IV	0	0	1	1

4th graders used "living organism type + animal type", followed by "animal type + plant type". (iii) The 6th graders were more consistent; 2/3 of them used "living organism type + animal type + plant type".

(4) When solving the problem of whether an animal or plant was a living organism, the children used a total of 11 forms of thinking: 3 were single types, which appeared among the 2nd, 4th and 6th graders. 4 were combinations of 2 types and 3 were combinations of 3 types, each of which appeared in all the grades. The combination of all 4 types was used only among the 6th graders.

4. Aboriginal Children's Application of the Concept of Living Organisms

A. Identification of Living Organisms and Living Things

Children were asked to discriminate between "living organisms" and "living things" by comparing 5 objects of life unknown to them. The results are as follows (Table 9):

(1) Children did best in the case of cushiony mosses, liverworts and slugs. Next was filamentous green algae. Crustaceous lichen was the most difficult.

(2) As for "living things" versus "living organisms", regardless of grade or the object, children did better for "living things" than for "living organisms".

(3) According to grade, when it came to identifying "living things", the more senior the grade, the better the performance, generally. But in identifying "living organisms" this was not the case. The 4th graders were not better than the 2nd graders.

(4) Most children knew that cushiony mosses, liverworts, slugs, and filamentous green algae were "living things", but they did not necessarily know that these were "living organisms". As for crustaceous lichen, most did not know it was living, nor knew it was a living organism.

B. Attributes of Living Organisms and Living Things

The attributes and reasons used by the children in identifying living organisms and living things can be grouped into the following 7 categories:

(1) Life: Children thought something was a living organism or living thing because it possessed life. For example, "It will die", "It lives in this world", etc.

(2) Animal or plant characteristics: Children classified something as a living thing or living organism because it had animal or plant shape, function or class. For example, "It has leaves", "It drinks water",etc.

(3) Growth and development: For example, "It grows", "It will sprout", etc.

(4) Habitat: Children classified something as a living organism or living thing because it was found in a life supporting environment. For example, "It grows on rock", "It lives in water",

Table 9. Number of Aboriginal Children in Each Grade Who Identified Objects of Life as "Living Thing" or "Living Organism"

	grade			
objects of life	2nd (N=12)	4th (N=12)	6th (N=12)	total (N=36)
cushiony moss:				
living thing	12	11	11	34
living organism	10	9	10	29
liverwort:				
living thing	9	11	12	32
living organism	9	9	11	29
filamentous green algae:				
living thing	6	8	10	24
living organism	4	8	7	19
crustaceous lichen:				
living thing	4	4	3	11
living organism	4	3	3	10
slug:				
living thing	9	12	12	33
living organism	7	6	10	23

etc.

(5) Personal experience: For example, "I've seen this", "I've eaten it".

(6) Reproduction: For example, "It's born", etc.

(7) Others: Children used other reasons or personal misconceptions to classify something as a living organism or living thing. For example, "It's green", "It floats on water", etc.

An analysis of the percentages of each of the above categories and distribution among each grade is presented in Fig. 5. It shows that:

(1) Children cited more reasons for "living things" than they did for "living organisms".

(2) Children mainly relied on "animal and plant characteristics", "growth and development", "personal experience" and "habitat".

(3) In the "life" category, children performed differently than in the other categories because of the questions asked: "Is it living?" and "Is it a living organism?" For the former, children tended to think in terms of the attributes of living. For the latter, they tended to consider " If it is living, it has life". This difference made children use the "life" category more for "living organisms" than they did for "living things".

(4) Other than the "life" category, all the other 6 categories were used more frequently for "living things" than for "living organism" .

(5) In the "animal and plant characteristics" category, regardless of their grades children used it to classify "living things" with a high percentage (94%). However, in classifying "living organisms" the percentage was only 58%.

(6) "Personal experience" saw the greatest difference in use in classifying "living organisms" and "living things". The percentage for "living things" was 69%, with at least half of each grade relying on it. However, only 14% used personal experience to classify "living organisms".

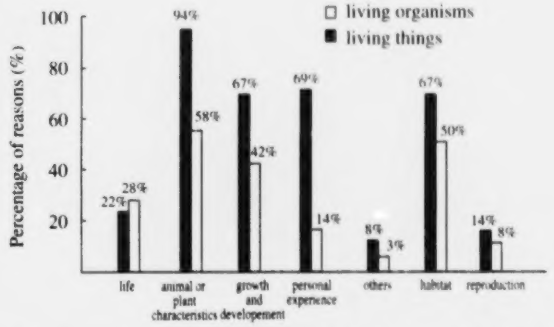


Fig. 5. Percentage of reasons used by aboriginal children to identify living organisms and living things.

IV. Discussion

Based on the above results,this study made the following findings:

1. Comprehension of "Living Organisms", "Living", and "Life"

Living organisms show the characteristics of living or having life. The attributes for "living organism", "living", "life" are not different but "life" and "living" are everyday colloquial terms. The formation of the concept comes from interaction between individuals and their environment and gradually matures with age. "Living organism" is mainly used in the educational environment. The acquisition of this concept comes during the learning process of education. Since the three terms have a common concept, children can use them interchangeably. In research on non-aboriginal children's concept of life, Huang (1993) used "living organisms", "non-living things", and "things of life" interchangeably in his interviews, and children had no problem understanding that the terms mean the same thing. Yet our study found that aboriginal children have a different comprehension of the three terms. The degree of familiarity was: "living" > "life" > "living organisms". This difference in familiarity is probably the result of: (1) Inferior comprehension of "life" caused by the influence of aboriginal language and culture. "Living" and "life" are both colloquial terms in Chinese culture so non-aboriginal children are accustomed to using them in describing an object. In the Taya language, however, there is only the term "living" ('mulus) and no such term as "life", which made the aboriginal children less likely to use it in expressing concepts. Hence the comprehension of "life" was not as good as that of "living". (2) The reason for poor comprehension of "living organism" probably originated in the learning process where this concept was handed down without direct experience. The children of this study frequently used personal experience such as "seen" or "eaten" to explain "living". Yet for "living organisms", children rarely cited such reasons, indicating unfamiliarity based on a lack of firsthand experience.

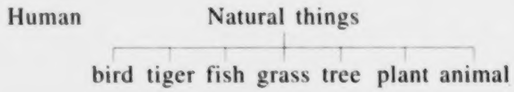
This study also found that aboriginal children used more animal items and fewer plant items in illustrating their concept of "living organism". This phenomenon of knowing animals better than plants is consistent with previous researches work (Lin & Yamasaki, 1986; Huang, 1987; Chen, 1989; Ryman, 1974a; Stavy & Wax, 1989) and shows that children's greater familiarity with animals than with plants is a common widespread phenomenon. Even the aboriginal children who live in a more natural environment follow this pattern.

2. Attributes of Living Organisms

In general, children of all grades frequently used "movement" to classify animals, and "growth" to classify plants as living organisms. Even the older children did not use biological attributes much. This was consistent with the findings of Huang (1993), Tamir *et al.* (1981), Stepans (1985), and Stavy & Wax (1989) that comprehending living organisms is as difficult for children everywhere as it is for non-aboriginal and aboriginal Taiwanese children. Besides the above two attributes, a high percentage of aboriginal children used animal and plant characteristics and habitats as living organism attributes, especially animal behavior and plant habitat. Behavior such as aggressiveness, movement and eating were found quite frequently in previous researches on animism, and were included among activity attributes (Wang, 1993; Su,1968; Russel & Dennis, 1939; Bruce, 1941). However, habitat and living environment were little mentioned. The percentage, if it occured at all, was very low (O-Saki & Samirdoen, 1990). The use of environment as a living organism attribute by aboriginal children (for example, "grass grows in soil", "vegetable grows in garden", "snakes hide in grass") indicated that their thinking concerning living organisms was different from that of the non-aboriginal children.

3. Classification of Living Organisms

As for the class concept of living organisms, this study found that the children were ignorant of the attributes and scope of classes. Children knew that human, animal, bird, plant, tree, grass and flower were living (that they possessed life) but they did not know that these living things all belonged to the class of "living organisms". Neither were they aware that there is a hierarchical relationship between human and animal, or between tree and plant. They believed that all living things are under the class of natural things. Their classification system is as follows:



This single-leveled classification structure is very similar to that of New Zealand children as discovered by Bell (1981). However, there are some differences. Our aboriginal children did not think of "human" as a living organism. They believed humans are humans. Humans are living but are not living organisms. This difference might have stemmed from the belief of aboriginal culture that a human is a unique being apart from other living organisms. It might also have stemmed from language differences. In the Chinese language, living and living organism are two different terms, whereas in the English language, living and living thing share a common linguistic symbol. This difference in linguistic expression might be why aboriginal children could not realized that a human is living and therefore can be classified as a living organism. Another difference from the New Zealand children is that the younger aboriginal children tended to think of animals as living organisms, while the older children tended to think of plants as living organisms. This discrepancy might stem from their learning process. The biology portion of natural science courses for the lower grades covers animals more, while the higher grade material covers more on plants. Also, the fact that the concept of class relationship between "living organism", "plants" and "animals" is not often properly clarified may be a factor.

4. Identification of Living Organisms

When it came to identifying something as a "living organism", the aboriginal children's process and reasons for giving a particular response followed an order of difficulty as follows:

(1) They can tell that something "Is not a living organism" easily.

↓

(2) They can tell that something "is a living organism" somewhat easily.

↓

(3) They can list "examples of living organisms" less easily.

↓

(4) They can recite a "biological definition" with some difficulty.

↓

(5) They can give a "biological definition" with great difficulty.

It was easier for the children to identify that something was not a living organism, than that it was to identify a living organism.

5. Characteristics of Living Organism Thinking

From the aboriginal children's judgment of and justifications for something being a living organism, we could see that their thinking might have the following characteristics:

(1) Lacking a concept of class-inclusion
The children generally thought of animal and plant items such as bird, fish, animal, tree, grass, plant, as all being on the same level as "animal" and "plant" and equal to "living organism". They were not aware that there is a hierarchical relationship. This was particularly so among the younger children. When asked "Is it a living organism?", they intuitively interpreted the question as "Is it equivalent to living organism?", rather than (as an adult would) "Does it belong to the class of living organisms?. This lack of the concept of class-inclusion might have caused the children's difficulty in comprehending "living organism".

(2) Self-centered
From the interviews, we found that most of the younger children tended to be strongly self-centered. Russell & Dennis (1939) found that during the early development stage, children tend to think of things that are useful or impeccable as living. Our aboriginal children were even more subjective. They were human-centered, dichotomizing things into "useful" and "useless", "good" and "bad". Those they thought were useful to humans, or considered in a positive way, were living organisms. Those that were bad, or thought of in a negative way, were not living organisms.

(3) Relying on experience
The children's concept of living organisms was very vague. They did not know what the critical attributes were. The living organism attributes they used were often all the possible life or non-life characteristics. This is a probabilistic perspective on life.

(4) Environmental attachment
Compared with non-aboriginal children, aboriginal children's life attributes possessed more superficial qualities, such as animal and plant properties and physical structures. What was even more different from non-aboriginal children was that the aboriginals were strongly biased toward the environment of living things, believing that the environment of living things was, if not a living thing itself, at least the foundation of life. The children's thinking followed two patterns:

(i) Association of life:
Thinking that there is an association between the environment and living things, believing living things and the growing environment are both living organisms. Hence, "The sun gives light to trees, so trees can grow", therefore sun is a living organism. "A mountain grows trees, a river has fish and plants", therefore mountains and rivers are also living organisms.

(ii) Foundation of life:
Thinking that the environment is an important attribute of life and believing that the environment where a living organism lives is an important attribute of the organism itself (because if the living organism "leaves it will wither, it will die"). Therefore an environmental attachment is an important basis for identifying living organisms.

V. Conclusions and Suggestions

1. Conclusions

(1) The aboriginal children had a different comprehension of the concepts "living organism", "living", and "life". Language, culture, and learning experience might have been the most important factors influencing this.

(2) In classifying living organisms, the aboriginal children tended toward using a single-leveled classification structure.

(3) The living organism attributes used by the aboriginal children were not consistent with those used in the natural science courses for elementary schools. The living organism attributes they used most were "movement" and "growth". They also emphasized the relationship between "living organisms and environment".

(4) The children had four types of thinking when identifying living organisms: (i) living organism type, (ii) animal type, (iii) plant type, and (iv) non-living organism type. The children's pattern of thinking was usually a combination of two or more of the above four types but a different combination for each grade. The major patterns were:

(i) 2nd grade: (a) living organism type + animal type; (b) animal type + non-living organism type.

(ii) 4th grade: (a) living organism type + animal type; (b) living organism type.

(iii) 6th grade:living organism type + animal type + plant type

(5) When identifying living and non-living organisms, the aboriginal children showed the following degrees of familiarity: They can tell that something "is not a living organism" > Can tell that something "is a living organism" > Can list "examples of living organisms" > Can recite a "biological definition" > Can give a "biological definition"

(6) The most often cited reasons for identifying "living organisms" and "living things" were: (i) animal and plant characteristics, (ii) growth and development, (iii) habitat, and (iv) personal experience. There was a great discrepancy in using "personal experience" for "living organisms" and for "living things". The children rarely relied on personal experience in identifying "living organisms", but often in identifying "living things".

2. Suggestions

Based on our findings, we suggest the following for future teaching methodology:

(1) Improve children's language ability.
In this research, we found that aboriginal children used short sentences, lacked vocabulary, and were imprecise in expression of meaning. Therefore, improving the children's language ability would be helpful to the acquisition of the living organism concept.

(2) Strengthen teachers' understanding of aboriginal culture.
Teachers in the aboriginal elementary schools are mostly non-aboriginals, with a non-aboriginal way of thinking. Teachers should have an understanding of aboriginal culture so that they can work from a pro-cultural basis and properly convey the information contained in their teaching materials.

(3) It would be helpful to the children's acquisition of knowledge if teachers do the following when teaching:

(i) Provide examples and non-examples of concepts.
The acquisition of concepts is a process of discrimination and generalization. If teachers do not provide enough examples and non-examples for children to discriminate and generalize, misconception is likely to occur.

(ii) Establish a hierarchical relationship of concepts.

(iii) Provide children with the opportunity for "hands-on" experience

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山地兒童生物概念及生物分類之研究

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摘　要

本研究以花蓮縣山地國小二、四、六年級學生共36名爲對象，研究山地兒童“生物”概念之理解與應用。在採用二階段個別晤談，分析熟悉物與不熟悉物的生命屬性歸類後，有如下發現：兒童在生物的分類思考上有四種模式：(1) 生物 (2) 非生物 (3) 動物 (4) 植物，各年級兒童均以二種以上的組合思考生物屬性，在“生物”及生命的屬性上，「運動」與「生長」最爲普遍，然而低年級兒童多以動物屬性指認“生物”，而高年級兒童則多以植物屬性指認生物。此外，兒童在“生物”概念上少用來自個人經驗的屬性，而“活的”概念則相反。在生物的類別階層上，兒童常將樹、草、鳥、魚等視爲與“植物”、“動物”同等地位，不知其有隸屬關係。概念之深層與精緻並未有隨年齡升高而發展的現象。對於錯誤概念之來源，生命歸屬與認知發展、語言關係，本研究亦於文中提出討論。

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An International Investigation of Preservice Science Teachers' Pedagogical and Subject Matter Knowledge Structures

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ABSTRACT

The nature and development of an international sample of preservice science teachers' subject matter and pedagogical knowledge structures were assessed as they proceeded through student teaching. Twelve American and 14 Taiwanese preservice science teachers were asked to create representations of their subject matter and pedagogical knowledge structures before and after their student teaching experience. They also participated in a videotaped interview concerning knowledge structure representations immediately following student teaching. Qualitative analyses of knowledge structure representations and transcribed interviews with and between subjects were performed. Initial knowledge structures were typically linear and not coherent. Subject matter representations were stable, while pedagogy structures were susceptible to change, in the American sample, as a consequence of teaching. The American preservice teachers perceived pedagogy and subject matter as distinct and exerting separate influences on classroom practice, while the Taiwanese sample consistently exhibited difficulty in separating subject matter from pedagogy. Differences between the nature and development of the knowledge structure representations of the two groups were related to both cultural differences and differences in approaches to teacher preparation between the two countries. Taken within the context of prior research, the results support the assertion that a clear relationship exists between the complexity of teachers' knowledge structures and subsequent translation into classroom practice. Given that only one teacher preparation program from each country constituted the sample for the investigation, the reader is cautioned against over-generalizing the results to Taiwan and the U.S. in general. However, this initial cross-cultural investigation does raise some questions concerning the differences in approach to teacher education in Taiwan and the U.S.

Key Words: teachers' knowledge structures, teacher education

I. Introduction

Recent concerns about the quality of teacher education programs (Carnegie Forum, 1986; Holmes group, 1986; Kennedy, 1990) and the evaluation of teaching (Shulman, 1986, 1987) have focused attention on the subject matter and pedagogical knowledge of teachers. As a consequence, many states have increased subject matter requirements for admission to teacher education programs. These increased requirements have taken the form of mandatory degrees in subject matter and/or subject matter competency examinations (e.g., National Teacher Examination) for prospective teachers. Such changes in policy have been made in spite of the fact that prior attempts to relate quantitative-oriented measures of what teachers know (e.g., GPAs, college credit hours, degrees attained) with measures of effective teaching have rarely produced relationships of strong, practical significance (Brophy & Good, 1986).

The results of previous research, however, have not caused educators and policy makers to abandon the rather intuitive notion that a teacher's subject matter knowledge necessarily influences classroom practice. Rather, it has been recognized that the "older" process-product oriented research paradigms (most of which were quantitatively-oriented) are not sufficient to answer questions concerning teachers' subject matter knowledge, its formation, and its potential impact on classroom practice. Prior research, whether quantitative or qualitative, has yielded little more than relationships among superficial attributes of teachers' thinking and classroom behaviors. Consequently, older research paradigms have yielded to more in-depth qualitative measures of teachers' subject matter conceptual frameworks.

Recent attempts to explore teachers' conceptual understanding of subject matter have used a wide variety of approaches, notably semantic networks, word associations, concept maps, and various versions of card sorting tasks (Baxter, Richert, & Saylor, 1985; Hashweh, 1986; Hauslein & Good, 1989; Hauslein, Good, & Cummins, 1992; West, Fensham, & Garrard, 1985; West & Pines, 1985; White & Tisher, 1985; Wilson, 1989; among others). Although such approaches are often used in concert with interview protocols, respondents are typically asked to organize and/or categorize topics or themes provided by the researcher in order to elucidate underlying subject matter structures. Although the data yielded by the aforementioned techniques are qualitative in nature, the structure imposed on data collection arguably compromises the benefits and purpose of using a qualitative research design. To date, relatively few studies have avoided the pitfalls of limiting subjects' representations of content knowledge to an a priori list of topics when assessing development over time.

Although the growth and role of subject matter knowledge within teachers' professional development is presently the source of much research and controversy, the parallel development and role of pedagogical knowledge, with few exceptions (Hoz, Tomer, & Tamir, 1990; Lederman, Gess-Newsome, & Latz, 1994; Morine-Dershimer, 1989), and the interaction of these two domains of knowledge has yet to be systematically analyzed. Furthermore, the nature and development of pedagogy and subject matter knowledge structures among preservice science teachers in different countries is a totally uncharted area of investigation.

The purpose of this international investigation was to assess the nature, development and changes of preservice secondary science teachers' subject matter and pedagogical conceptions/knowledge structures as they proceeded through their student teaching experience. In particular, this investigation attempted to answer the following questions: (1) What is the nature/form of preservice science teachers' subject matter and pedagogical knowledge structures? (2) What is the source(s) of these knowledge structures? (3) Are these knowledge structures stable during student teaching?, and (4) What is the relationship between these knowledge structures and how do they relate to the act of teaching? In addition to combined data analyses, each of the research questions was used to examine the similarities and differences between the two cultural groups (and distinct approaches to teacher preparation) represented in the sample.

For the purposes of this investigation, "knowledge structure" refers to the knowledge an individual possesses and the manner in which this knowledge is organized. Our research definition is intentionally broad and it is recognized that we might be more accurate in describing our teachers' knowledge as "conceptions" (and at times we use the terms synonymously) of subject matter and pedagogy as opposed to formal knowledge structures. Whether the label "knowledge structure" or "conception" is preferred, such referents should not distract the reader from the primary focus of this investigation: the nature, development, and changes of preservice science teachers' knowledge of subject matter and pedagogy as they proceed through the student teaching experience.

II. Design

1. Sample

Twelve preservice secondary school science teachers (seven biology, three general science, one chemistry, and one physics; seven males, five females) from the U.S. and 14 preservice teachers (seven physics, four biology, and two chemistry; eight males, four females) from Taiwan were studied as they proceeded through their student teaching. The American students were completing a one-year Master of Arts in Teaching (MAT) program and possessed at least a B.S. degree in their subject matter field (two had a M.S. degree and one a Ph.D.). The Taiwanese students were in their final year of a four-year teacher preparation program at a normal university. The Taiwanese preservice teachers possessed the U.S. equivalent of a B.S. plus 15 credit hours in their subject matter specialty. Consequently, all of the preservice teachers

(American and Taiwanese) possessed a level of subject matter knowledge well above that of most preservice teachers. In particular, preservice teachers in the U.S. commonly possess only a B.S. or less within their subject matter specialty. Even with the proliferation of MAT programs, preservice teachers commonly do not possess much more than a B.S. degree within their science specialty. Each of the preservice teachers in this investigation was seeking initial certification.

There were significant differences between the teacher preparation programs undergone by the U.S. and Taiwanese preservice teachers prior to their student teaching experience, which may have contributed significantly to several of the noted differences between the two samples. The duration of the teacher preparation program for the American preservice teachers was one year and consisted primarily of subject-specific pedagogy courses, with subject matter background required as a prerequisite for admission. Student teaching was performed during the third quarter of a four-quarter program. In contrast, the Taiwanese students proceeded through a four-year teacher preparation program in which both subject matter and pedagogy were addressed throughout the four years. Science pedagogy was emphasized in subject matter courses as well as within specific teaching method courses. As a consequence of Changhua University of Education's emphasis on the preparation of teachers, subject matter courses were consistently taught in a context focusing on the ultimate teaching of subject matter to secondary students. Therefore, pedagogy was both implicit and explicit within subject matter courses. Neither the subject matter courses nor pedagogy courses in Taiwan or the U.S. explicitly emphasized or discussed the "structure" of science disciplines or science pedagogy. Student teaching was completed at the end of the fourth year. At the time of student teaching, however, each of the groups of preservice teachers had received instruction in learning theories, teaching methods and strategies, microteaching, and had participated in field-based practica.

The student teaching experiences also differed significantly between the two programs. The American preservice teachers worked full time in a school setting and assumed full instructional responsibility for 3-4 classes (two preparations). Full instructional responsibility was assumed for a period of 10 weeks. The Taiwanese students worked full time in a school setting for only one month, during which time they assumed full instructional responsibility.

The two researchers (one from Taiwan and one from the U.S.) were well acquainted with the preservice teachers as a consequence of their significant instructional responsibilities within their respective programs. We believe that the rapport between researchers and subjects served to facilitate the gathering of in-depth, accurate data and did not act as a hindrance.

2. Data Collection and Analysis

The case study design specified by Bogdan and Biklen (1992) was considered most appropriate for this investigation. In this particular instance, the case study focused on two culturally different groups of individuals who were proceeding through two distinctly different teacher preparation programs and student teaching experiences. Data was collected and analyzed in two phases. Of initial interest was whether preservice science teachers possess coherent conceptions and/or structures for their subject matter specialty and pedagogical knowledge. This question was addressed primarily in Phase I. The additional questions proposed by this study were addressed in Phase II.

A. Phase I.

Two weeks prior to the beginning of student teaching, each subject was given approximately 30 minutes to answer the following questions:

(1) What topics make up your primary teaching content area? If you were to use these topics to diagram your content area, what would it look like?

(2) Have you ever thought about your content area in the way you have been just asked to do so?

One week later, each subject was asked to answer the same questions, but with "important elements/concerns of teaching" substituted for the phrase related to primary teaching content area. The preservice teachers were asked to answer Question #1 again immediately following the completion of student teaching. For the second administration of the questionnaires, Question #2 was replaced with: "Have your views changed? If so, how and why?" Naturally, questionnaires were written and filled out in the native languages of the preservice teachers.

It should also be noted that no specific methods of formatting or organizing the subject matter and pedagogy "diagrams" were suggested to the preservice teachers. In addition, the preservice teachers were told that their descriptions of subject matter and pedagogy could focus on topics, themes, processes, strands, etc. and could be "represented" by use of a diagram, concept map, picture, description, or in any manner with which they felt comfortable.

Overall, it was felt that this methodology was superior to past attempts to assess subject matter and pedagogical knowledge structures because it gave respondents the freedom to select their own topics, themes, processes, or strands, etc. (as opposed to card sorts) and to organize these elements of knowledge in any manner with which they felt comfortable (as opposed to artificially forcing representations into categories, hierarchies, dimensions, or particular formats). It was hoped that this approach would provide a clearer portrait of the preservice teachers' conceptions/structures of subject matter and pedagogy. All representations and written text produced by the Taiwanese preservice teachers were translated into English prior to data analysis by the first author.

Qualitative analysis of the data collected during this phase (two administrations each of the subject matter and pedagogy questionnaires) attempted to derive any evident patterns between and within both groups of preservice teachers' stated subject matter and pedagogical structures. This initial analysis (conducted by the first author) served as a guide for additional data collection during a follow-up interview which took place one to two weeks after the completion of student teaching.

B. Phase II.

Within two weeks following the completion of student teaching an attempt was made to assess changes in the preservice teachers' knowledge structures and clarify any patterns elucidated in Phase I. Each American subject was asked to participate in a 45-60 minute videotaped interview conducted by the first author, while the Taiwanese preservice teachers were interviewed by both researchers with the second author serving as translator. The interviews consisted of questions that asked the subjects to describe their current knowledge structures, discuss changes which had occurred and any reasons for these changes, discuss any relationships between the knowledge structures or between either knowledge structure and their teaching, and their feelings about completing the questionnaire. During the interview, the previously completed knowledge structure diagrams/representations were displayed and discussed individually and as a group. Finally, all subjects were given an opportunity to revise the second diagrams/representations produced for subject matter and pedagogy to conform to any changes which might have occurred since its completion.

Importantly, the interview was also viewed as a means to compensate for any confusion created by the pencil-and-paper questionnaire (either with respect to the respondents' reactions or the researchers' interpretations of responses). The problems associated with researchers' attempts to infer individuals' conceptions, knowledge, and beliefs solely from pencil-and-paper materials have been clearly recognized (Lederman, 1992). All interviews were transcribed (and translated when necessary) for analysis. Data were compared within and between individuals to derive any evident patterns for this particular group of preservice teachers.

Both phases of data analysis were conducted by the first author with the second author independently analyzing both the Taiwanese and American preservice teachers' knowledge structure representations and videotaped interviews. The second author is fluent in both Taiwanese and English. The independent findings of the two researchers were compared, contrasted and discussed. Given the cultural differences between the two groups of preservice teachers and the researchers, this was a critical step in the analysis of the data. There was no attempt to achieve total agreement between the perceptions of the two researchers. Such an attempt would only have served to eradicate the richer understanding which was gained from the different perspectives brought to the data analysis by the use of multiple researchers (Bogdan & Biklen, 1992; Eisner, 1991; Lincoln & Guba, 1985). The result was a clearly more comprehensive and deeper understanding of the preservice teachers' conceptions, while at the same time protecting interpretations from being overly influenced by the perspective of an individual researcher (Lederman & Gess-Newsome, 1991; Miles & Huberman, 1984).

III. Results and Discussion

The reported results represent the culmination of several rounds of data analysis, by each of the two researchers, and have been organized in terms of the initial questions guiding the investigation.

1. What is the Nature/Form of Preservice Science Teachers' Subject Matter and Pedagogical Knowledge Structures?

Interview responses indicated that the preservice teachers were quite hesitant while completing the first (and sometimes the second) subject matter questionnaire. Many felt tentative or uncertain about what to write. They indicated that they had no problem understanding the question or task at hand, but rather were hesitant about the content (and quality) of their responses, as indicated by the following representative comments:

> I knew what I was supposed to do. Still, you don't want to look like you don't know what you're talking about. I know my subject matter well, but I worry about communicating my knowledge to others. (American Preservice Teacher)
>
> Knowing your subject matter is important. It would be very bad if a teacher did not know his subject. I did not want you to think I did not know my subject. (Taiwanese Preservice Teacher)

In short, both groups of preservice teachers were concerned that the questionnaire was a test of their subject matter understanding. No similar hesitancy or concern was expressed with respect to the pedagogy questionnaire, but the Taiwanese preservice teachers expressed much difficulty in conceptualizing or discussing pedagogy apart from their subject matter.

> I am to become a physics teacher. So, I do not know how to think about teaching separately from physics. (Taiwanese Preservice Teacher)
>
> This was a lot easier than the other questionnaire. I've seen so many teachers in my life, it's pretty easy to figure out what it's about. (American Preservice Teacher)

Initial subject matter representations were primarily listings of discrete topics or science courses taken at the university. The Taiwanese group, however, consistently included various pedagogical concerns (e.g., teaching approach, level of students) within their subject matter representations. The inclusion of pedagogical concerns within the subject matter representations of the Taiwanese preservice teachers was a consistent pattern throughout the investigation, serving to further reinforce the inability of the Taiwanese group to separate conceptions of subject matter from the teaching of the subject matter.

The pedagogical structures were primarily listings of the teacher-oriented components of instruction. Student-oriented components of instruction (such as motivation, prior knowledge) were given little or peripheral attention by the American group while the Taiwanese preservice teachers consistently took students as a focal point. The presence of integrative curriculum themes (e.g., nature of science, S-T-S) or connections between or within the components of either subject matter or pedagogical structures were not commonly noted by either group of preservice teachers. Again, it is important to note that the oral instructions provided with the questionnaires explicitly emphasized that the word "topics" need not be taken literally and that respondents should feel free to include topics, themes, processes, or strands, etc. In addition, it was also emphasized that representations need not be "diagrams," and could take whatever form most accurately portrayed each individual's conceptions.

Organizational patterns were quite traditional with respect to subject matter. In general, subject matter structures were presented in three general formats: discrete (Fig. 1), simple hierarchy (Figs. 2 and 3), and web-like (Fig. 4). The Taiwanese group overwhelmingly presented subject matter in the form of simple hierarchies (again, with pedagogical factors included) while their American counterparts could be primarily characterized as striking a balance between discrete formats and simple hierarchies. The web-like format was clearly not common within either group of preservice teachers. Naturally, the labels used to

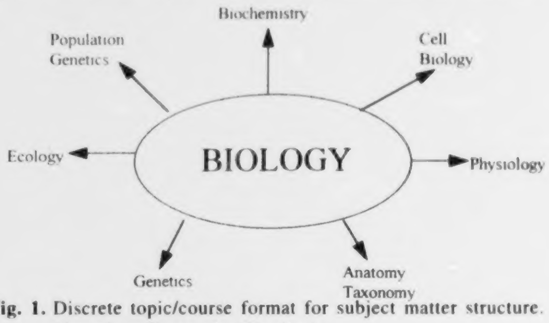

Fig. 1. Discrete topic/course format for subject matter structure. (American Preservice Teacher)

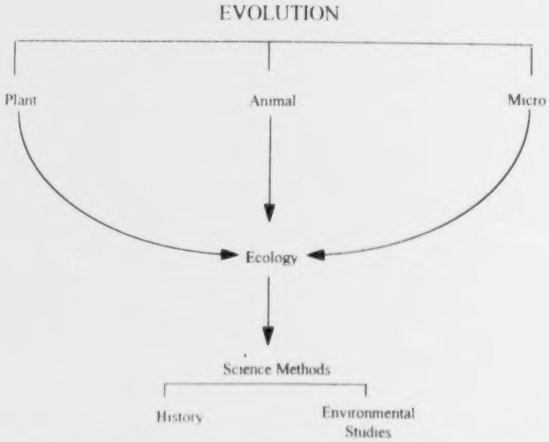

Fig. 2. Simple hieracrchy format for subject matter structure (American Presservice Teacher)

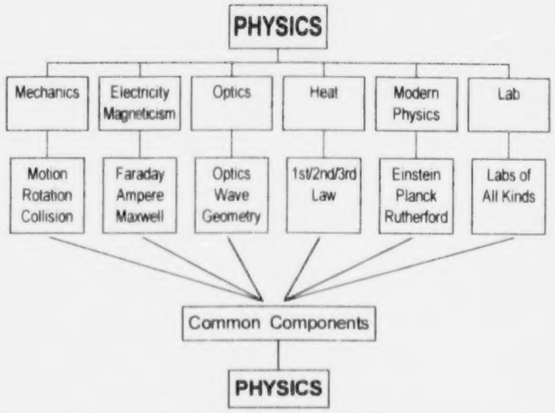
PHYSICS
Mechanics
Electricity Magneticism
Optics
Heat
Modern Physics
Lab
Motion Rotation Collision
Faraday Ampere Maxwell
Optics Wave Geometry
1st/2nd/3rd Law
Einstein Planck Rutherford
Labs of All Kinds
Common Components
PHYSICS

Fig. 3. Simple hierarchy format for subject matter structure (Taiwanese Preservice Teacher)

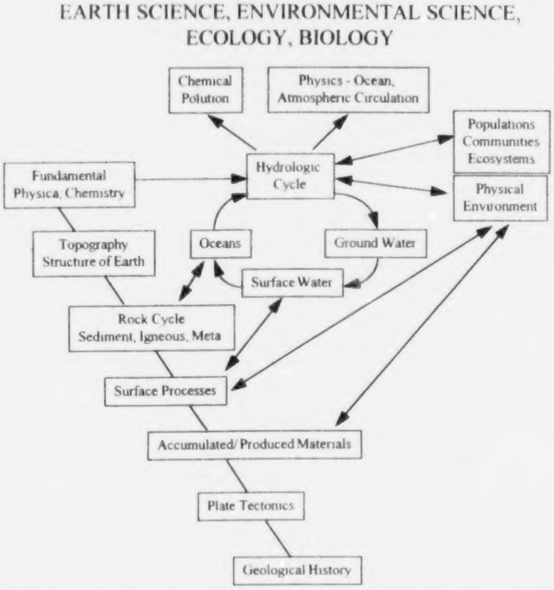
EARTH SCIENCE, ENVIRONMENTAL SCIENCE, ECOLOGY, BIOLOGY
Chemical Polution
Physics - Ocean, Atmospheric Circulation
Populations Communities Ecosystems
Fundamental Physica, Chemistry
Hydrologic Cycle
Physical Environment
Topography Structure of Earth
Oceans
Ground Water
Surface Water
Rock Cycle Sediment, Igneous, Meta
Surface Processes
Accumulated/ Produced Materials
Plate Tectonics
Geological History

Fig. 4. Web-like/interrelated format for subject matter structure. (American Preservice Teacher)

describe the appearance of subject matter representations were a matter of convenience. As opposed to the descriptive labels, of more significance are the clear distinctions among the representations. It is important to again note that the preservice teachers were allowed to represent subject matter in any way that they felt best depicted their understanding. Although all of the teachers were familiar with concept mapping, none chose to follow the concept mapping approach of describing the meaning of connecting arrows and/or connecting lines. When asked for the meaning of these connections during interviews, the preservice teachers (both Taiwanese and American) consistently described the meaning as a "connection or relationship" with no further elaboration. Rather, the responses tended to focus on the general organizational pattern of the representation, with the nature of the pattern having implications for the type of relationship depicted by connecting arrows and/or lines (e.g., in a hierarchical depiction, arrows or lines extending from a superordinate idea were intended to denote inclusion of those subordinate concepts/ideas listed below).

Pedagogical structures tended to be organized as web-like/interrelated representations of concerns, knowledge, and/or activities performed (Fig. 5), with students conspicuously absent as a primary focus in the representations of the American group (but as a clear focal point in the representations of the Taiwanese group) or as discrete "listings" of teacher-focused responsibilities and activities (Fig. 6). Again, descriptive labels were for convenience and should not distract from the clear visual and substantive distinctions among representations. As with the subject matter representations, connecting lines and arrows were described as simply denoting relationships, with the overall organizational pattern of the representation providing further clarification of the nature of the

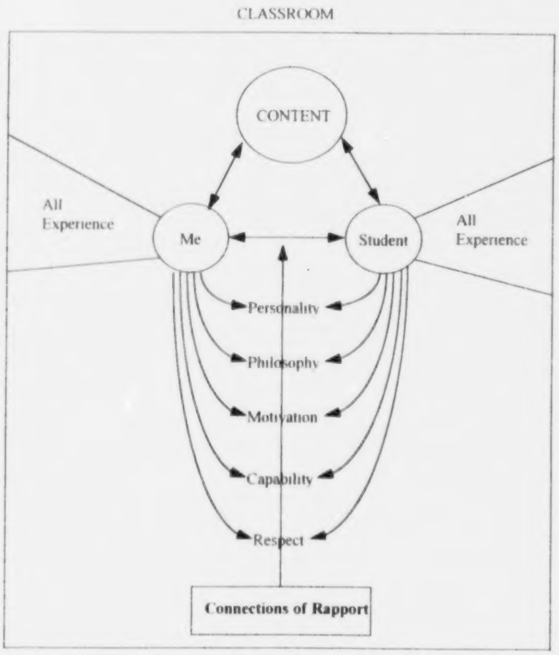
CLASSROOM
CONTENT
All Experience
Me
Student
All Experience
Personality
Philosophy
Motivation
Capability
Respect
Connections of Rapport

Fig. 5. Web-like/interrelated format for pedagogical structure. (Taiwanese Preservice Teacher)

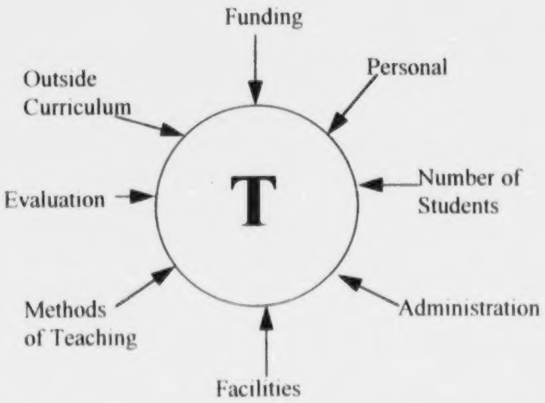

Fig. 6. Discrete responsibilities/activities format for pedagogical structure. (American Preservice Teacher)

relationship.

2. What is the Source(s) of these Knowledge Structures?

When asked about the source of their subject matter structures, many student teachers admitted, as might be expected, that the portrayed elements and organizational scheme came from college courses and that the representations were only tentatively delineated without any conscious rationale. For example, comments along the lines of the following were common:

> I just put down the things we learned and did in my physics classes. Everything I know about physics comes from my teachers and books I have read. (Taiwanese Preservice Teacher)

> How I view earth science is what I learned in school. Probably from all of my schooling, but mostly from what I had in college. (American Preservice Teacher)

These findings suggest that preservice science teachers (regardless of nationality) are not being presented with an overt or covert structure (or global conceptual framework) of subject matter (or at least one that is recognized) as part of their content preparation. The reader is also reminded that both groups of preservice teachers possessed subject matter knowledge backgrounds exceeding that included as part of an undergraduate degree in the U.S. Consequently, the lack of any recognizable subject matter structure does not appear to be unique to those with only undergraduate level preparation in subject matter. The reader is reminded that neither subject matter nor pedagogical structures were stressed within the teacher preparation programs of the Taiwanese or American preservice teachers. Consequently, the representations given indicate the individual knowledge structures formulated by the preservice teachers as they proceeded through subject matter and pedagogy courses.

When asked about the source of their pedagogy knowledge structures, the preservice teachers uniformly referred to introductory education courses and personal experiences as a student:

> I have been a student and a student in education courses. Where else could I better learn about teaching? (American Preservice Teacher)

> My science education courses at the university have taught me what I need to know to be a good teacher. (Taiwanese Preservice Teacher)

When asked if they had ever thought about their subject matter specialty or pedagogy in the manner requested by the questionnaire, only one of the American preservice teachers, and none of the Taiwanese, admitted having previously thought about his subject matter in this manner. No individuals of either group admitted having done so for their knowledge of pedagogy. This finding is quite consistent with the lack of explicit attention to knowledge structures in both the Taiwanese and American teacher preparation programs. Contrary to the findings of previous research which has relied on card sorting tasks and other possibly restrictive assessment procedures (Baxter *et al.*, 1985; Hashweh, 1986; Hauslein *et al.*, 1992; Hoz *et al.*, 1990; Wilson, 1989), but consistent with research using more open-ended assessments (Lederman *et al.*, 1994), the preservice teachers appeared to possess no coherent, as typically defined by curriculum reform movements (Kennedy, 1990), or carefully considered structure for their subject matter. Furthermore, the topics, themes, and processes, etc. used in the representations of this group of preservice teachers exhibited little resemblance to the *a priori* elements/topics used in previous investigations. Perhaps the more directed approaches (e.g., concept maps, card sorting tasks, semantic maps) used in previous investigations of subject matter structures served to create the resulting structures (with respect to both content and organization) and did not necessarily provide an objective assessment. With respect to pedagogy, the results of this investigation were consistent with those obtained in previous investigations (Lederman *et al.*, 1994; Morine-Dershimer, 1989).

3. Are these Knowledge Structures Stable During Student Teaching?

Overall, virtually no changes were noted in the subject matter representations of either group. Although changes were clearly noted in the pedagogical knowledge structures of the American group, the representations of the Taiwanese group remained quite stable. The lack of change in subject matter conceptions of either group, despite the planning and implementation of lessons during student teaching, is a finding that contradicts an emerging and consistent body of literature (e.g., Hauslein *et al.*, 1992; Gess-Newsome & Lederman, 1993; Lederman *et al.*, 1994). When asked to discuss their conceptions of subject matter during the interview, typical responses clearly reinforced the impressions provided by the written representations.

> How I view biology really hasn't changed much. I pretty much think of things the same as I said before. (American Preservice Teacher)

> I am probably a bit more frustrated than before I taught. But I still view the teaching of physics the same. (Taiwanese Preservice Teacher)

The interviews definitively indicated that these preservice teachers had not altered their views toward the subject matter in response to the use of the subject matter in the context of teaching. Of particular interest here is the Taiwanese preservice teacher's reference to "the teaching of physics." The representation and related discussion was intended to be limited to the subject matter. However, as mentioned before, the Taiwanese preservice teachers consistently exhibited a subconscious (and often conscious) difficulty or unwillingness to consider subject matter as separate from the teaching of the subject matter. The significance of this clear difference from the American preservice teachers will be addressed in the *Implications* section of this paper.

Pedagogical representations became increasingly more complex for the American preservice teachers. A proliferation of student-focused components (e.g., motivation, learning styles, relevance, etc.) as well as additional teacher roles (e.g., friend, counselor) and responsibilities were clearly evident. Of most significance was a general shift away from linear representations of pedagogical knowledge to more web-like frameworks which placed the students and their concerns at the center (Figs. 7 and 8). For example, the individual who created Fig. 7 had initially created Fig. 6.

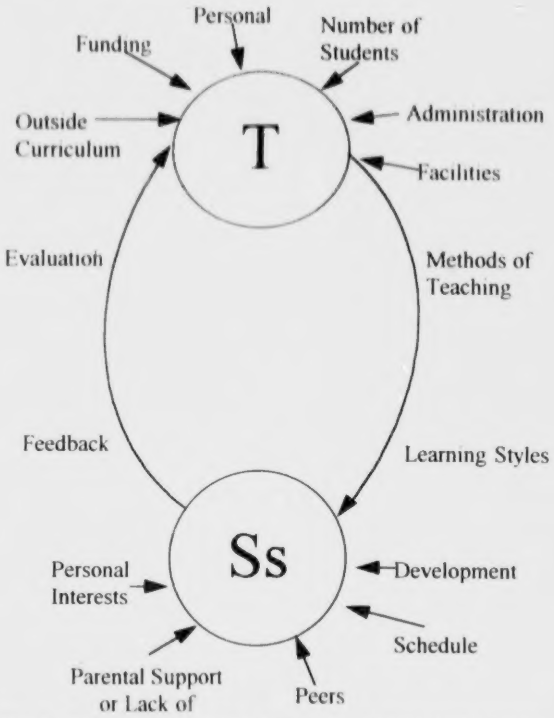
Funding
Personal
Number of Students
Outside Curriculum
T
Administration
Facilities
Evaluation
Methods of Teaching
Feedback
Learning Styles
Personal Interests
Ss
Development
Schedule
Parental Support or Lack of
Peers

Fig. 7. Web-like/interrelated format for pedagogical structure (American Preservice Teacher)

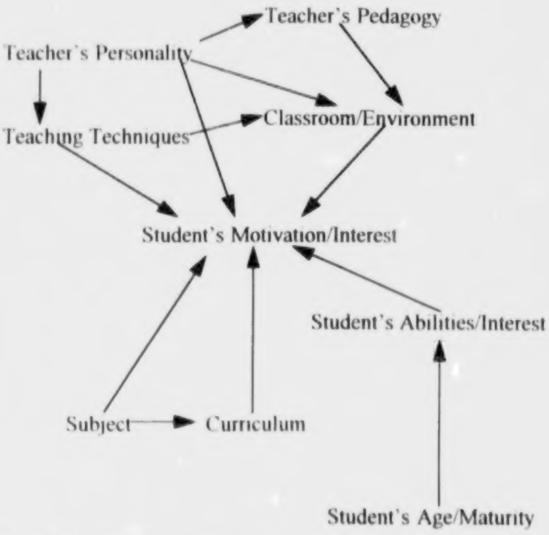
Teacher's Pedagogy
Teacher's Personality
Classroom/Environment
Teaching Techniques
Student's Motivation/Interest
Student's Abilities/Interest
Subject
Curriculum
Student's Age/Maturity

Fig. 8. Web-like/interrelated format for pedagogical structure. (American Preservice Teacher)

In general, the pedagogical representations of the Taiwanese preservice teachers remained the same as before student teaching. The representations of the American preservice teachers became more similar to the initial and stable representations of their Taiwanese counterparts. The changes in representations of pedagogy by the American group appeared to be influenced by the planning and implementation of actual lessons. A common explanation for the change in the American preservice teachers' pedagogical structures is illustrated by the following comments:

> The students demand your attention. You couldn't ignore them if you wanted to. (American Preservice Teacher)

> You can talk about the importance of the students all you want. You may even believe you have a focus on students' needs. But it's all abstract until you're actually face to face with 30 of them. (American Preservice Teacher)

In short, the American preservice teachers reinforced one of the commonly voiced shortcomings of campus-based teacher preparation courses. It is interesting to note, however, that the Taiwanese preservice teachers initially placed students as a focal point in their pedagogical structures and continued to do so throughout the duration of the investigation.

4. What Is the Relationship between these Knowledge Structures and How Do They Relate to the Act of Teaching?

During the interview the preservice teachers were asked to discuss and relate to each other the set of four questionnaires (two subject matter and two pedagogy questionnaries). Whenever overlaps or similarities between the two types of structures were noted, the subjects were asked if they could be combined into one diagram or whether a combined depiction would be more accurate. The American preservice teachers uniformly responded negatively:

> It makes more sense to me to keep the two separate. After all, knowledge of subject matter and how you teach subject matter are two different things. (American Preservice Teacher)

> They're different things. When I teach I need to know my subject matter, but my knowledge of teaching tells me how to present what I know. (American Preservice Teacher)

On the other hand, the Taiwanese students were clearly less willing to distinguish between subject matter and pedagogy. As noted previously, they continued to integrate pedagogy into their conceptions of subject matter:

> There is much overlap, of course. I have learned science because I wanted to become a science teacher. I learned science always with a view of teaching it. (Taiwanese Preservice Teacher)

The American preservice teachers clearly perceived pedagogy and subject matter knowledge as separate entities which were applied in an integrated manner during teaching, while the Taiwanese preservice teachers perceived the two in a much more integrated manner. During the interview, individuals were provided with a hypothetical teaching situation in which students are unable to understand a particular aspect of subject matter. When asked about what their response would be, the two groups of preservice teachers described their decision making process quite differently:

> If students do not understand, I must find where the confusion is. To do this involves my knowledge of physics teaching. It is not a problem of subject matter or pedagogy. (Taiwanese Preservice Teacher)

> High school students do not really know much biology. If they do not understand something, I must rely primarily on my knowledge of teaching. My knowledge of subject matter is important, because it gives me alternative examples to use, but it is my knowledge of teaching that lets me choose the correct solution to the problem. (American Preservice Teacher)

In short, even when presented with a hypothetical classroom situation/problem, the American group tended to conceptualize the influence of subject matter knowledge and pedagogy separately, while their Taiwanese counterparts exhibited a more integrated approach to the two knowledge domains.

As previously mentioned, neither group of preservice teachers altered their conceptualizations of subject matter knowledge in response to their exposure to public school students and the planning and implementation of science lessons. This finding does not support prior suggestions (Hauslein & Good, 1989; Hauslein *et al.*, 1992) that it may be impossible to view subject matter as separate from the manner in which it is, or will be, used. The act of teaching and/or thinking about how one will teach subject matter did not appear to have a significant influence on the way subject matter was conceptualized among these two groups of preservice teachers.

The pedagogical structures of the American group were seen to shift toward a focus on student concerns following the student teaching experience. This finding is consistent with assertions made by Lederman

& Gess-Newsome (1991) concerning the shift in concerns of preservice science teachers toward students as soon as they begin to teach lessons in actual field settings.

When specifically asked if their stated subject matter and pedagogical knowledge structures were evidenced in their teaching, both groups of preservice teachers were confident that each type of knowledge (i.e., subject matter and pedagogy) was reflected in how and what they taught:

> Of course, at least I hope, my teaching is based on what I know and think. (Taiwanese Preservice Teacher)
>
> I teach chemistry the way I view chemistry and I teach in a way that reflects my philosophy of teaching. I believe modeling to be very important in chemistry and it is continually stressed. I believe students learn best if they are actively involved and so I organize my class in that way. (American Preservice Teacher)

These results are consistent with a large body of literature on the relation of subject matter structures and teaching (e.g., Baxter *et al.*, 1985; Hashweh, 1986) and contradicts recent research (Gess-Newsome & Lederman, 1993; Hollingsworth, 1989) which indicates that preservice teachers are too overwhelmed by day-to-day instructional responsibilities to adequately and consciously incorporate integrated subject matter structures into daily instruction. The present results concerning the translation of subject matter and pedagogy knowledge structures into classroom practice must, however, be interpreted with extreme caution. The discrepancies between teachers' self-reports and actual classroom practices have been well documented. Additional research of this nature that includes actual classroom observations should be pursued.

IV. Implications for Science Education

Prior to any elaboration of the implications of this investigation, the reader is reminded that only one teacher preparation program from the U.S. and Taiwan were investigated. Consequently, it would be inappropriate to generalize differences between the two samples to obtain definitive differences between Taiwanese and American teacher education. Nevertheless, the two teacher preparation programs investigated were significantly different in approach and several of the noted differences in findings are seemingly related to programmatic differences.

It does not appear that these preservice science teachers, regardless of nationality, possess "well-formed" or highly integrated subject matter or pedagogical knowledge structures. Consistent with previous research (Gess-Newsome & Lederman, 1993; Hauslein *et al.*, 1992; Lederman *et al.*, 1994), the subject matter knowledge structures that do exist are largely the result of college course work and are often fragmented and disjointed with little evidence of coherent themes. Consequently, the currently popular policy of requiring stronger subject matter backgrounds for preservice and inservice teachers, as a means of resolving the myriad of concerns about the quality of science instruction, may not be an effective approach. Such an approach, as seen with this group of preservice teachers, would most likely not lead to the development of the highly prized integrated subject matter conceptions advocated by prominent science education reform movements (A.A.A.S., 1989; NRC, 1996; NSTA, 1993). Furthermore, the preservice teachers investigated in similar studies (Gess-Newsome & Lederman, 1993; Lederman *et al.*, 1994) possessed far less extensive backgrounds in science but developed more integrated subject matter structures in response to the planning and implementation of instruction. In addition, it is important to note that the American preservice teachers studied in the present investigation completed the same professional teacher education coursework (e.g., methods, microteaching, practicum, etc.) as those in the studies by Gess-Newsome & Lederman (1993) and Lederman *et al.* (1994), with the only difference being the extent of subject matter background (i.e., degrees attained and course credit hours).

It is possible that the more extensive academic backgrounds of both the Taiwanese and American preservice teachers (which is consistent with current teacher preparation reforms) may result in the development of more firmly entrenched and inflexible conceptions of the subject matter. Consequently, although few would argue with the desirability of science teachers with extensive academic backgrounds, it might be that present approaches to college-level science instruction promote the development of relatively inflexible cognitive structures which are at odds with the integrated framework required for the implementation of currently advocated curriculum reforms. Although acquiring a relatively static view of one's subject matter as a consequence of a more extensive academic background is a problem in need of solution, the situation is further exacerbated if the nature of the structure is less than desirable. Since any significant reform in the instructional approach that currently typifies college science teaching seems unlikely, responsibility for stimulating students for reflecting on their subject matter (in an effort to promote the development of more integrated and flexible knowledge structures) seems to be most appropriately placed within the domain of the science educator. It is possible that repeated opportunities for reflecting on one's subject matter, as it is being learned, may be sufficient to provide preservice teachers with a coherent schema for their subject matter and allow them to integrate more of the information presented in their science courses. Certainly, the possible benefits to be derived from increased reflection upon subject matter within science education courses is an area needing further research.

The inability of the American preservice teachers to present a coherent conceptualization of pedagogy prior to student teaching is not surprising. As prior research has indicated (Lederman & Gess-Newsome, 1991), a well formed pedagogical knowledge structure should not be expected without actual experience with "real" secondary students. Other than simply increasing the length of field experiences (as many teacher education programs are already doing), it may be necessary to provide increased opportunities for preservice teachers to conduct systematic classroom observations (Good & Brophy, 1991) and reflect upon instructional sequences.

The American and Taiwanese preservice teachers clearly conceptualized pedagogy, and the relationship of pedagogy and subject matter, differently. Initially, the Ameican group gave students only peripheral attention, while the Taiwanese group took students as a focal point (a view the American group adopted following student teaching). Furthermore, the Taiwanese group consistently exhibited difficulty in conceptualizing subject matter as separate from the teaching of the subject matter, while the American group clearly preferred to keep subject matter knowledge and knowledge of pedagogy distinct. It appears that distinct differences between the professional teacher education programs undergone by the two groups of preservice teachers may be responsible for the noted differences in conceptions of pedagogy and subject matter. In particular, the American group was completing a MAT program. This program requires a B.S. degree (or beyond) in one's subject matter specialty for admission. The program does include an additional nine graduate hours in the subject matter, but is primarily focused on science pedagogy with subject matter knowledge assumed to have been acquired prior to entrance. Virtually all of the American preservice teachers had decided to become secondary school science teachers during their senior year in college or following graduation. The Taiwanese group, on the other hand, had been educated in a system much like the historic American Normal School. These students had decided to become teachers when they were completing their high school education, and spent much effort preparing for entrance examinations that would enable them to attend a college dedicated to the preservice education of teachers. Consequently, the Taiwanese preservice teachers received their subject matter background concurrently with their teacher preparation, and the subject matter was typically presented from the perspective of eventually having to teach it to others. Although this was not an experimental investigation, it does not take much to see why the Taiwanese students initially focused on students when conceptualizing pedagogy (while the American group did not) and experienced much difficulty in representing subject matter apart from its teaching (while the American group did not). Perhaps the U.S. may want to reconsider its current trend toward graduate level teacher preparation, with subject matter knowledge "front loaded," and focus specific attention on the conceptions of pedagogy and subject matter which are apparently needed to implement the currently popular reforms.

Keeping in mind the caution necessitated by the fact that classroom observations of these preservice teachers were not performed, the self-reported influence of preservice teachers' subject matter structures on classroom practice is consistent with much of the research on pedagogical content knowledge (Gudmunsdottir & Shulman, 1987; Hashweh, 1986; Shulman, 1987). However, the conclusions of American preservice teachers concerning the separate application of subject matter knowledge and pedagogical knowledge to instructional decisions are at odds with current thinking related to pedagogical content knowledge. Again, the Taiwanese preservice teachers were more integrated in their application of pedagogy and subject matter to classroom decisions. It may be that teacher preparation in a manner similar to the Normal University is more consistent with promoting pedagogical content knowledge than current approaches to achieving this end. Again, however, it must be noted that the Normal University approach to teacher education experienced by the Taiwanese group did not appear to alleviate the problem of discrete and fragmented conceptions of subject matter. This finding serves as a clear reminder that significant reform in science teacher education will necessarily involve full cooperation between subject matter specialists and science teacher educators.

The apparent contradiction with those of Gess-

Newsome & Lederman (1993) of the findings related to subject matter structures is particularly intriguing. The subjects in that study included global, integrative (and arguably abstract) curriculum themes such as the nature of science and science-technology-society interactions in their subject matter structures. Such themes were virtually absent from the representations of both the American and Taiwanese preservice teachers, making their knowledge structures relatively simple in comparison. Consequently, it is quite possible that the ease with which a subject matter structure affects classroom practice (if at all) is as much a function of the relative complexity of the knowledge structure as it is of curriculum constraints, administrative policies, management concerns, etc. Indeed, the findings of this investigation concerning the complexity of a teacher's subject matter structure are supported by the recently reported investigation of Lederman *et al.* (1994). However, given that the data concerning translation of subject matter conceptions/structures into classroom practice was self-reported in nature, additional research that includes direct classroom observations should be performed in order to focus on the relationship between knowledge structure complexity and classroom practice. The possible importance of the complexity of one's knowledge structure is especially problematic since many of the new reforms in science education seem to depend on the incorporation of highly integrative themes such as the nature of science and science-technology-society interactions. If such highly complex and integrated subject matter structures are so difficult to translate into classroom practice, our expectations with respect to the ability of beginning and novice teachers to implement curriculum reform may have to be drastically reconsidered.

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職前科學教師教學與學科知識結構的國際研究

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摘 要

職前科學教師的學科知識和教學知識結構之本質與發展，是針對二十六位我國、美國兩地的職前教師，在進行實習教學之中評鑑而得。有十二位美國的職前教師和十四位我國的職前教師參與本項研究，研究的重點主要在教學實習前後，將他們的學科知識和教學知識以適當的圖形加以繪製出來。此外，也針對這些實習教師的教學表現進行晤談，並將晤談加以錄影。然後，將所收集的知識結構之表徵與晤談內容轉錄資料，在職前教師之間和每一位職前教師本身，運用質的研究法加以比較分析。研究結果顯示，這些職前教師起始的知識結構，基本上，呈現了線性，也缺乏同調。在實習教學之後，美國職前教師之學科知識表徵呈現穩定狀態，然而，教學知識結構發生改變。而且，美國職前教師認爲教學與學科知識是屬於不同領域的知識，而且對課室教學的影響也是各自獨立的。對於要把學科知識和教學知識加以區別，我國的職前教師則一致地認爲有相當程度的困難。對於我國和美國兩地的職前教師之教學知識和學科知識結構的本質與發展之差異，應係關聯到兩國文化的基本差異，及師資培育的方式之差異使然。若考慮將以前研究的情境因素考慮在內，本研究的結果仍然支持如下的主張：教師知識結構之複雜性與其轉化爲課室教學的表現是存在著明確的關係。

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(Invited Review Paper)

Empirical Review of Unidimensionality Measures for the Item Response Theory

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Abstract

This study reviewed the performance of various measures of unidimensionality by using simulated data sets which were in compliance with the two-parameter normal ogive model conditions. The investigated measures were based on homegeneity, factor analysis, item fit statistic, and Stout's DIMTEST methodology. The simulated data sets varied in terms of the item-ability correlation range and test length.

Based on the overall results of this empirical review, the following suggestions are offered regarding use of different unidimensionality measures. To arrive at a unidimensional and homogenous set of items, an index based on average inter-item correlation is better than one based on the coefficient alpha. In determining whether a data set satisfies an assumption of unidimensionality in terms of a single common factor model, the principal axis method performs much better than do the other methods in terms of examining the extracted eigenvalue pattern based on tetrachoric correlation matrices. To ensure that test items hold essential local independence, Stout's DIMTEST factor procedure is preferred not only to the prior knowledge procedure, but also to other unidimensionality measures. To assess whether an individual item fits the two-parameter normal ogive model, a two-stage procedure consisting of goodness-of -fit by chi-square statistic and root mean square standardized residual may be used when $n \geq 20$.

Key Words: homogeneity, item fit statistic, maximum likelihood-SMC analysis, principal component analysis, principal axis analysis, Stout's DIMTEST statistic, two-parameter normal ogive model, unidimensionality measures

I. Introduction

In testing theory, the assumption of unidimensionality refers to a set of test items sharing a single latent trait; it is this unobservable quantity which accounts for item performance correlations. The assumption of unidimensionality ensures a meaningful score interpretation for measurement situations in which comparisons are based on test scores which consist of item score composites (McNemar, 1946). In addition, the assumption is considered a crucial component of unidimensional item response theory models (Lord & Novick, 1968). Several researchers have shown that when data sets violate this assumption, larger measurement errors occur which jeopardize meaningful inferences concerning the relative standings of examinees in terms of certain traits (Wang, 1988; Hattie, 1984). Stout (1987) summarized three reasons for determining data set unidimensionality : 1) to avoid test contamination by another trait; 2) to indicate if a test measures two or more traits (requiring a split into subtests for analysis and interpretation); and 3) to ensure in advance the appropriateness of applying unidimensional item response models.

According to Hattie (1985), over 80 indices have been proposed for the purpose of determining unidimensionality-- all of them were developed from methods based on homogeneity, principal component and factor analyses, and fit statistics under one- or two-parameter logistic models. Example of indices corresponding to these methods include coefficient alpha or average inter-item correlation (Cronbach, 1951; Novick & Lewis, 1967), first- to second- eigenvalue ratio (Lord, 1980; Reckase, 1979), a chi-square test on the number of common factors (Bock & Lieberman, 1970), and the sum of mean-squared or absolute residuals (McDonald, 1981; Rogers, 1984; Wright & Stone, 1979).

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Hattie (1985) compiled a list of unidimensionality indices and summarized their problems as follows: 1) alpha is not a monotonic function of unidimensionality whereas mean inter-item correlation is influenced by communality; 2) the eigenvalue magnitude is dependent on which correlation type is analyzed while, at the same time, the chi-square test is sensitive to sample size; and 3) indices of the sum of mean-squared or absolute residuals are obtained using an ad hoc approach to assessing item behavior, and sampling distributions are un-known.

Hattie (1984) had previously conducted a study in which he generated item responses via a multivariate, three-parameter logistic latent trait model to assess the adequacy of selected indices in determining unidimensionality. His results showed that, relative to indices based on other methods, an index of the sum of absolute residuals based on the two-parameter latent trait model was more efficient in discriminating between cases with one and more than one latent trait.

Stout (1987) took into consideration the inherent nature of test item performance being multiply determined to explore whether a set of test items fit an 'essential unidimensionality' --that is, the existence of one (and only one) 'dominant' factor exerting influence on item responses. According to the principle of essential local independence, Stout developed a T index to assess essential unidimensionality as used in the DIMTEST procedure (Stout, *et al.*, 1992; Nandakumar & Stout, 1993). DIMTEST is a nonparametric test procedure in the sense that Stout's statistic T is derived by making no assumption about the shape of either the underlying ability distribution or the item response function.

The performance of Stout's statistic T has been investigated extensively in a variety of test settings using both Monte Carlo-simulated and real data (Nandakumar, 1991, 1993, 1996; Nandakumar & Stout, 1993; Stout, 1987; De Champlain & Gessaroli 1991; Hattie, *et al.*, 1996). The studies yielded consistent results showing that Stout's statistic T 1) strongly maintained a desired Type I error rate; 2) was capable of discriminating between one and more than one dimension underlying test data; 3) obtained robust performance over a variety of ability distribution shapes. These results support the dominance of Stout's statistic T over the other methods for assessing the lack of fit of test item unidimensionality. However, Lin (1997) Described the following three caveats regarding conceptual and technical considerations.

First, the DIMTEST procedure, based on the principle of essential local independence, takes the mathematical form of:

$$\frac{1}{n(n-1)} \sum_{1 \le i \ne j \le n} \left| Cov(U_i, U_j \middle| \boldsymbol{\Theta} = \boldsymbol{\theta} \right| \approx 0,$$

where n is test length **(1)**

Equation (1) states that, on average, the covariances of any two item responses (U_i, U_j) approach zero when conditioned on the dominant ability vector $\boldsymbol{\theta}$. In terms of (1), the DIMTEST procedure seeks to determine what is called "essential dimensionality"--the minimum dimensionality accounting for item responses. In contrast, under the two-parameter normal ogive model (Lord & Novick, 1968) the mathematical meaning of unidimensionality for a test consisting of n dichotomously-scored items is defined as:

$$g(\mathbf{u}) = \int_{-\infty}^{\infty} g(\mathbf{u}|\theta) f(\theta)\, d\theta \quad \text{for all } \mathbf{u}$$

$$= \int_{-\infty}^{\infty} \left\{ \prod_{g=1}^{n} [P_g(\theta)]^{u_g} [1 - P_g(\theta)]^{1-u_g} \right\} f(\theta)\, d\theta \quad \textbf{(2)}$$

where

$$\begin{cases} \mathbf{u} \equiv (u_1, u_2, \ldots, u_n) \text{ denotes any pattern of} \\ \quad n \text{ binary responses, and} \\ g(\mathbf{u}) \text{ denotes the marginal distribution of } \mathbf{u} \end{cases}$$

$$P_g(\theta) \equiv \int_{-\infty}^{a_g(\theta - b_g)} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}}\, dt, \quad \textbf{(3)}$$

$$\text{where} \begin{cases} b_g \equiv P_g(b_g) \equiv 0.50 \equiv \text{item difficulty,} \\ a_g \equiv \sqrt{2\pi} P_g'(b_g) \equiv \text{item discrimination, and} \\ P_g' \text{ is the derivative of } P_g'. \end{cases}$$

Equation (2) states that the marginal distribution $g(\mathbf{u})$ of $\mathbf{U}=(U_1, U_2, \ldots, U_n)$ for a randomly chosen examinee can be expressed as the conditional distribution of $g(\mathbf{u}|\theta)$ and a prior distribution $f(\theta)$ for the random variable of latent ability Θ.

Compared to the unidimensional IRT model, the DIMTEST procedure is weaker in that it only looks for the minimum dimensionality necessary to satisfy an assumption of essential local independence. The DIMTEST procedure and IRT model stem from somewhat different conceptualizations in terms of factors which influence item performances. For example, the local independence assumption under the unidimensional IRT model demands that covariance of each item pair be zero when conditioned on a single latent ability.

Second, most examinations of DIMTEST performance have used simulation data sets generated according to either a one-dimensional, three-parameter logistic model for a Type I error rate study or a multidimensional, three-parameter logistic model for a power study. These simulation studies generate zero-one item responses by comparing the probability magnitude of correct /incorrect responses with a random number between 0 and 1 generated from a uniform distribution. It should be pointed out that such a procedure fails to characterize the hierarchical Baysian structure underlying the ITR dichotomous data responses.

Third, Stout's statistic $T=\frac{T_L-T_B}{\sqrt{2}}$ for assessing essential unidimensionality requires the selection of an initial set of M test items in order to form an assessment subtest for computing the statistics T_L in T. Specifically, T's goodness of performance is subject to the extent to which the chosen M items are dimensionally homogeneous. Stout (1987) has suggested use of either factor analysis or prior knowledge for the selection of the M item test set. Most of the studies cited above used the DIMTEST factor procedure for this purpose and found that the desired Type I or power rate of Stout's statistic was obtainable. The extent to which Stout's statistic T obtains a similar level of performance when the M items are selected by means of prior knowledge is unknown.

In view of these three concerns, the intent of the present study was to examine the performance of Stout's statistic T using data sets complying with the sufficient conditions of the two-parameter normal ogive model in Eq. (3). In other words, the data sets must satisfy the hierarchical Baysian structure from a normal distribution of ability, and the dimensionality of test items must equal one. As such, this examination was analogous to a Type I error study. A secondary goal was to examine the performance of the unidimensional index in terms of methods based on the factor analysis, homogeneity, and item fit statistics; this performance has not been examined empirically using a data structure consistent with the sufficient conditions described for Eq. (3).

II. Methodology

The two-parameter normal ogive model of Eq. (3) may be inferred from the regression assumptions by imposing a continuous /latent variable Y_g' and a constant γ_g for item g; from this, it is possible to determine whether examinee a will answer item g correctly via such relations as $\text{Prob}(U_g=1|\theta)=\text{Prob}(Y_g'>\gamma_g|\theta)$ and $\text{Prob}(U_g=0|\theta)=\text{Prob}(Y_g'\leq\gamma_g|\theta)$. Lord (1968, 1980) pointed out that given that θ is normally distributed in the group tested -- that is, $f(\theta)=\varphi(\theta)$ in (2) -- the observed multivariate distribution $U_1, U_2, \ldots, U_n$ for a set of n items can be arisen from some multivariate normal distribution of $(Y_1', Y_2', ..Y_n')$ by dichotomizing them by $(\gamma_1, \gamma_2, \ldots,\gamma_n)$. The observed multivariate distribution $(U_1, U_2, \ldots, U_n)$ for any set of data is determined by γ_g as well as by the intercorrelations ρ_{ij}' of Y_i' and Y_j' ($i\neq j$; $i, j=1, 2, \ldots, n$); and the resultant data is consistent with the two - parameter normal ogive model and the assumption of unidimensionality. In this particular case, unidimensionality may be interpreted from the Spearman one-common factor model, since θ acts as the common factor underlying test item performance. In addition, a parameter such as item factor loading ρ_g' or item discrimnation a_g can be inferred from a factor analysis of tetrachoric correlations between item U_i and item U_j.

The above theoretical relationships provide the guidelines for generating zero-one data sets. For the sake of clarity, they are summarized in the diagram below (Fig. 1):

	Hypothetical Level $(Y_1', Y_2', \ldots, Y_g', \ldots, Y_n')$ $(\gamma_1, \gamma_2, \ldots, \gamma_g, \ldots, \gamma_n)$	Observable Binary Data Set U_g-data
	n items	n items
N	$(1, 2, \ldots, g, \ldots, n)$	$(1, 2, \ldots, g, \ldots, n)$
θ_1	$(Y_{11}', Y_{12}', \ldots Y_{1g}', \ldots, Y_{1n}')$	$(U_{11}, U_{12}, \ldots, U_{1g}, \ldots, U_{1n})$
θ_2	$(Y_{21}', Y_{22}', \ldots Y_{2g}', \ldots, Y_{2n}')$	$(U_{21}, U_{22}, \ldots, U_{2g}, \ldots, U_{2n})$
θ_3	$(Y_{31}', Y_{32}', \ldots Y_{3g}', \ldots, Y_{3n}')$	$(U_{31}, U_{32}, \ldots, U_{3g}, \ldots, U_{3n})$
$\vdots$	$\vdots$	$\vdots$
θ_a	$(Y_{a1}', Y_{a2}', \ldots Y_{ag}', \ldots, Y_{an}')$	$(U_{a1}, U_{a2}, \ldots, U_{ag}, \ldots, U_{an})$
$\vdots$	$\vdots$	$\vdots$
θ_N	$(Y_{N1}', Y_{N2}', \ldots Y_{Ng}', \ldots, Y_{Nn}')$	$(U_{N1}, U_{N2}, \ldots, U_{Ng}, \ldots, U_{Nn})$
	$Y_1', Y_2', \ldots, Y_n'$	$U_1\ U_2 \ldots U_n$

$$\begin{matrix}Y_1'\\ Y_2'\\ \vdots\\ Y_n'\end{matrix}\left|\begin{matrix}\text{product-moment}\\ \text{corr. }\rho_{ij}'\\ \text{between }Y_i'\text{ and }Y_j'\end{matrix}\right|\xleftarrow{\textit{estimate}}\begin{matrix}U_1\\ U_2\\ \vdots\\ U_n\end{matrix}\left|\begin{matrix}\text{tetrachoric}\\ \text{correlations}\\ \text{between }U_i\text{ and }U_j\end{matrix}\right|$$

$$Y_g'=\rho_g'\theta+\sqrt{1-\rho_g'^2}E_g',\ g=1, 2, \ldots, n,$$

$$\text{where}\quad \rho_g'=\begin{cases}\text{item factorloadingon }\theta\\ \text{correlation between }Y_g\text{ and }\theta\\ \text{biserial -corr. between }U_g\text{ and }\theta\end{cases}$$

$$\text{and}\ E_g'=\begin{cases}\text{the unique random variable}\\ \text{the unique part of item }g\end{cases}$$

Fig. 1. Data structure consistent with the sufficient conditions for the two-parameter normal ogive model.

Readers are referred to Lin (1997) for a detailed description of the procedures used to generate U_g-*data* of zero-one responses that comply with the two-parameter normal ogive model. The following is a summary of the four major steps:

(1) N examinees are generated from a standard normal distribution of θ. A vector such as $\tilde{\theta}=[\theta_1, \theta_2, \ldots, \theta_a, \ldots, \theta_N]\sim\varphi(0,1)$ is produced.

(2) Random variates of $Y_1'|\theta_a, Y_2'|\theta_a, \ldots, Y_g'|\theta_a, \ldots, Y_n'|\theta_a$ are generated for examinee a's responses to the n items via the conditional normal distribution of $Y_g'|\theta_a$ having a mean of $\mu_{g|\theta}'=\rho_g'\theta$ and a standard deviation of $\sigma_{g|\theta}'=\sqrt{1-\rho_g'^2}$. Note that this step is completed for all N examinees.

(3) The constant vector $\tilde{\gamma}=[\gamma_1, \gamma_2, \ldots, \gamma_g, \ldots, \gamma_n]$ is obtained for the set of n items. This is possible due to the capability of determining γ_g from π_g according to the relation:

$$\pi_g \equiv \text{Prob}(U_g=1)=\frac{1}{\sqrt{2\pi}}\int_{\gamma_g}^{\infty} e^{-\frac{t^2}{2}}dt=\Phi(-\gamma_g)$$

(4) When $Y_{ag}'>\gamma_g$, the corresponding binary quantity $U_{ag}=1$; when $Y_{ag}'\leq\gamma_g$, $U_{ag}=0$. Comparisons are conducted relating each examinee's responses to each individual item.

In the present study, these four steps were followed in order to simulate five U_g-data sets-- that is, five matrices containing the zero-one responses of N examinees (ranging from 1000 to 2000) to n items (20, 30 and 40). For a test length of 20, three matrices were generated by varying the range of ρ_g' used in Step 2. For example, three sets of 20-ρ_g' were generated from a uniform distribution with limits falling within intervals of 0.05-0.95, 0.30-0.90, and 0.50-0.90. When n=30 or 40, only one set of ρ_g' was generated from a uniform distribution with limits falling within an interval of 0.05-0.95. The intent of this design was to determine whether the performance of Stout's statistic T and related measures was dependent on the test length, range of ρ_g', or both.

III. Data Analyses and Results

1. Methods Based on Stout's Statistic *T*

The analytic procedure of the DIMTEST statistic (Stout, *et al*., 1992) for testing the unidimensionality of a set of n dichotomously scored items (H_0:d=1) can be diagrammed as follows (Fig. 2.):

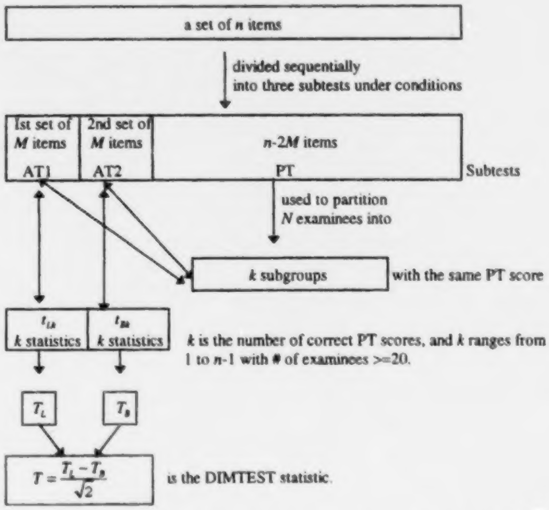
a set of n items
divided sequentially into three subtests under conditions
1st set of M items
AT1
2nd set of M items
AT2
n-2M items
PT
Subtests
used to partition N examinees into
k subgroups
with the same PT score
t_LK k statistics
t_BK k statistics
k is the number of correct PT scores, and k ranges from 1 to n-1 with # of examinees >=20.
T_L
T_B
T = (T_L − T_B)/√2
is the DIMTEST statistic.

Fig. 2. A flow chart of the analytic procedure of the DIMTEST statistic.

In the diagram, AT1 and AT2 represent Assessment Subtests 1 and 2, respectively, and PT stands for the Partitioning Subtest. The conditions imposed on the selection of two sets of M items are such that 1) the M items selected for AT1 are as unidimensional as possible and dimensionally distinct from the same test's n-M items ; 2) the set of M items selected for AT2 is dimensionally similar to the n-2M items , with difficulty levels as similar as possible to those of the AT1 items; and 3) the ideal M is $M\leq n/4$, where $n\geq 20$. The statistic T_B, which is used in T (the DIMTEST statistic), compensates for biases in T_L. It is to reject H_0:d=1 when $T>Z_\alpha$, where Z_α is the upper 100(1−α) percentile for a standard normal distribution, α being the desired level of significance.

In accordance with the conditions imposed on the DIMTEST statistic T, this study used sets of M=5, M=7, and M=10 for five sets of tests with lengths of 20, 30, and 40, respectively. In addition, all M items selected for AT1 were either chosen independently by the factor routine of the DIMTEST software (FA), or were based on a prior knowledge procedure which capitalized on the fact that the range of ρ_g' was simulated. With respect to the latter method, two sets of M items for AT1 were selected based on the degree of homogeneity. For example, one set contained items having the highest possible common-factor loadings (ρ_g'), representing the most homogeneous set (H1); the other set contained items with common-factor loadings spread over the range of ρ_g', thus representing the less homogeneous set (H2). In this manner, all three sets of *M* items for AT1 were selected for each of the five data sets.

Table 1 summarizes the results of Stout's unidimensionality test of the five test data sets based on a sample size of 2000, including such statistics as T_L, T_B, T and P-value, plus statistics associated with two AT1 and AT2 subtests obtained under the H1, H2, and FA procedures (including the item number, means of item loadings / difficulties, and mean differences between the two subtests). As shown in Table 1 , the H1, H2, and FA procedures yielded different sets of *M* items for AT1; consequently, *M* items for AT2 differed according to the selection conditions described above. In terms of the degree of homogeneity as measured by the mean of the common-factor loadings of AT1 items, it was found that H1 yielded significantly larger mean values compared to those associated with AT2 items, regardless of the test length. In contrast, mean differences of loadings between AT1 and AT2 under the H2 and FA procedures were negligible, again regardless of the test length. Examining the mean differences in item difficulty between AT1 and AT2, none were found among the three procedures.

Table 1 also shows that the calculated values of T associated with the five test data sets resulting from the H1 procedure ranged from 1.80 to 9.42 -- all larger than $Z_{0.05}=1.65$; the calculated values of T obtained from the H2 and FA procedures were all less than $Z_{0.05}=1.65$, with the exception of one whose T value following the H2 procedure was measured at 1.71 for a test length of 20, with ρ'_g generated from $U(0.05\text{-}0.95)$. That the H1 procedure yielded values different from those resulting from the H2 and FA procedures indicated that acceptance of $H_0{:}d=1$ is dependent on how the *M* items for AT1 are selected. In addition, since the primary differences among the H1, H2, and FA procedures center on the degree of homogeneity associated with AT1, it can be argued that Stout's unidimensionality test might be invalid in cases where AT1 items hold a high degree of homogeneity relative to the same test's n-M items.

2. Method Based on Item Fit Statistic

Since Eq. (3) is the model expectation for an item response, that is, $P_g(\theta)=E(U_g|\theta)$, the difference (residual) between expected and observed data can be used to examine item goodness-of -fit. If one set of items fits the two-parameter normal ogive model, including the unidimensionality assumption, then their residual values should be small. On the other hand , a large residual value indicates failure of the model in terms of goodness-of- fit. In accordance with this traditional argument, it is to compute the chi-square statistic for the mean squared error associated with any item. Since all of the simulated test data used in the present study were based on test lengths greater than 20, item fit statistics were computed with formulae from version 1.22 of the BILOG-3 program (Mislevy & Bock, 1990).

Table 2 lists the likelihood ratio chi-squares for individual items in the five sets of tests with lengths of 20, 30, and 40; asterisks mark poor-fitting items for which significant levels were less than 0.01. The table shows the poor-fitting item numbers to be 3, 2, 6, 3, and 6 for the five tests with lengths of 20, 30, and 40. Since the simulated test data were in compliance with the two-parameter normal ogive model, these results indicated that the likelihood ratio chi-square statistic invoked error misclassification.

Since the chi-square statistic is sensitive to tests with $n \geq 20$, a further examination of item fit was conducted for five subtests composed of items flagged as poor-fitting. As all of these subtests were very short; the fit test was based on the root mean square of the standardized posterior residual. As shown in Table 2, none of the residuals were greater than 2.0, indicating no problem with the goodness-of-fit of these items. This result was true for each of the four shortened subtests (note the lack of analysis for the subtest having only two items). It should also be noted that the root mean square standardized residual was sensitive to tests with $n \geq 20$ as well.

3. Methods Based on Factor Analysis

Since the simulation data sets were consistent with Spearman's one-common factor model, the author compared the performance of the unidimensionality measure based on the principal component (PC), principal axis (PA), and maximum likelihood (ML) methods (Harman, 1976). The primary distinction among the three methods comes from the amount of variance analyzed--that is, the number placed in the diagonal of the correlation matrix. Within the context of n items, the three models were addressed as follows:

$$\begin{cases} \text{PC: } U_i = a_{i1}F_1 + a_{i2}F_2 + \dots + a_{in}F_n \\ \text{PA: } U_i = a_{i1}F_1 + a_{i2}F_2 + \dots + a_{im}F_m \\ \text{ML: } U_i = a_{i1}F_1 + a_{i2}F_2 + \dots + a_{im}F_m + \dots + d_iQ_i \end{cases}$$

Table 1. Statistics Associated with: 1) Stout's DIMTEST Procedure for the Five Test Data Sets, and 2) AT1 and AT2 Subtests Obtained Using the H1, H2, and FA Procedures

			AT1			AT2			AT1-AT2					
			M item number	$\overline{loading}$	$\overline{diff}$.	*M* item number	$\overline{loading}$	$\overline{diff}$.	diff-Load	dif-diff.	T_L	T_B	T	*P*-Value
		H1	1 2 3 4 5	0.860	0.498	11 10 16 18 6	0.676	0.564	0.184	-0.066	8.86	6.32	1.80	0.04*
$n=20$	$\rho'_g=U(0.50-0.90)N=2000$	H2	1 5 10 15 20	0.716	0.529	12 4 16 18 8	0.688	0.585	0.028	-0.056	5.48	5.99	-0.36	0.64
$M=5$	mean=0.710	FA	13 3 11 9 6	0.752	0.438	14 8 20 2 12	0.696	0.450	0.056	-0.012	4.21	3.04	0.83	0.20
		H1	1 2 3 4 5	0.840	0.498	12 10 16 18 6	0 558	0.566	0.282	-0.068	10.80	4.83	4.23	0.00*
$n=20$	$\rho'_g=U(0.30-0.90)N=2000$	H2	15 10 15 20	0.624	0.529	11 4 16 18 6	0.600	0.555	0.024	-0.026	4.12	4.59	-0.33	0.63
$M=5$	mean=0.615	FA	19 17 10 18 8	0.498	0.492	13 12 7 1 9	0.678	0.560	-0.180	-0.068	0.88	3.83	-2.09	0.98
		H1	1 2 3 4 5	0.860	0.498	12 10 16 18 9	0.410	0.561	0.450	-0.063	13.87	2.18	8.27	0.00*
$n=20$	$\rho'_g=U(0.50-0.90)N=2000$	H2	15 10 15 20	0.536	0.529	11 2 16 18 6	0.518	0.555	0.018	-0.026	5.51	3.09	1.71	0.04*
$M=5$	mean=0.523	FA	14 8 6 7 16	0.536	0.354	17 9 20 15 2	0.428	0.366	0.108	-0.012	3.25	1.88	0.97	0.17
		H1	1 2 3 4 5 6 7	0.860	0.458	10 29 16 15 21 24 9	0.449	0.474	0.411	-0.016	15.52	5.95	6.77	0.00*
$n=30$	$\rho'_g=U(0.50-0.95)N=2000$	H2	1 5 9 13 17 21 25	0.590	0.379	26 3 6 20 18 16 12	0.547	0.389	0.043	-0.010	5.64	3.71	1.37	0.09
$M=7$	mean=0.515	FA	13 3 25 19 14 15 12	0.547	0.512	11 28 10 7 24 6 9	0.573	0.489	-0.026	0.023	3.99	3.71	0.20	0.42
		H1	1 2 3 4 5 6 7 8 9 10	0.847	0.438	25 24 20 38 37 40 33 29 28	0.311	0.457	0.536	-0.019	17.20	3.88	9.42	0.00*
$n=40$	$\rho'_g=U(0.50-0.95)N=2000$	H2	5 9 13 17 21 25 29 33 37	0.536	0.460	26 3 6 36 38 7 40 2 10 35	0.506	0.458	0.030	0.002	6.74	5.18	1.10	0.14
$M=10$	mean=0.502	FA	7 19 5 2 28 37 8 4 34 39	0.529	0.587	3 32 11 29 40 22 18 1 30 26	0.462	0.572	0.067	0.015	5.03	4.00	0.73	0.23

H1: AT1 *M* items having the highest values of common-factor loadings ρ'_g.

H2: AT1 *M* items spreading over the range of ρ'_g.

HA: AT1 *M* items selected by means of factor anlaysis of DIMTEST.

*: significant at 5% level.

Table 2. Chi-square Test of Individual Item Fits for the Five Test Lengths (20, 30, and 40 items), Including Root Mean Square Standardized Item Residuals

	ρ'_g=(0.50–0.90) n=20, N=1000		ρ'_g=(0.30–0.90) n=20, N=1000	ρ'_g=(0.05–0.90) n=20, N=1000		ρ'_g=(0.05–0.95) n=30, N=1000		ρ'_g=(0.05–0.95) n=40, N=1000	
items	Chisq	Residual*	Chisq	Chisq	Residual	Chisq	Residual	Chisq	Residual
1	19.4*	0.287	30.9*	49.8*	0.481	17.6*	0.343	28.8*	0.772
2	21.7*	0.196	15.2	20.9*	0.497	27.8*	0.383	11.7	
3	8.5		13.6	26.7*	0.495	11.3		11	
4	10.4		9.6	14.6		7.2		22.9*	0.958
5	9.1		10.1	13.9		11.6		17.5*	0.340
6	12.6		12.4	18.9*	0.310	8.8		10.4	
7	6.8		15.2	14.6		17.9		10.7	
8	14.0		10	22.2*	0.611	2.9		18.8	
9	17		12.9	13.4		6.2		16.6	
10	5.1		3.9	13.2		7.5		23.7*	0.438
11	12.1		9.4	5		13.2		7.9	
12	5.6		7.7	6.4		21.5*	0.953	7.2	
13	5.7		8.6	13.7		10.9		8.8	
14	6.6		4.3	4		10		5.9	
15	25.4*	0.632	28*	26.3*	1.042	14.1		6.4	
16	15.6		14.5	20		16.7		5.6	
17	4		1.3	8.5		18		16.9*	1.005
18	5.2		6.7	10.4		4.1		5.4	
19	4.1		7.7	8.5		8.3		5.4	
20	16.7		9	7.2		5.5		5.5	
21						5		10.8	
22						7.8		14.5	
23						10.4		8.7	
24						7		13.3	
25						5.3		13.5	
26						4.4		4.4	
27						9.1		14.3	
28						10.3		7.8	
29						15.5		6.7	
30						17.7		26*	1.550
31								6.1	
32								5.4	
33								10.1	
34								6.1	
35								6	
36								4.8	
37								8	
38								8.2	
39								17.4	
40								4.9	

*: significant at 0.01 level.

*: residual obtained by analyzing the shortened subtests consisting of items with an asterisk.

However, within a context of a unidimensional set of *n* items, the number of common factors extracted from each of the three methods should equal one if the method is indeed valid.

Table 3 summarizes the results of analyzing five tetra-corr matrices based on the five U_g-data sets, including associated eigenvalues and their patterns and the number of factors extracted under individual criterion sets according to each method. It is important to mention here that rows 3, 8, 13, 18, and 23 in Table 3 contain parameters which exhibit only a single, positive, non-zero characteristic root. The information in each row serves as a baseline reference for comparing the relative performance among the three factor analysis methods--PC, PA (Iterated principal axis), and ML-SMC (maximum likelihood with squared multiple correlation as a communality estimate).

As shown in the last column of Table 3, in terms of the number of retained factors, each of the three methods failed to display a one-common factor pattern

Table 3. Eigenvalues and Numbers of Factors Extracted from Five Tetrachoric Matrices Using Three Factor Analysis Methods for Tests with 20, 30, and 40 Items

	Range of ρ_g^t	Method of Factor		Eigenvalue pattern												# of factors
				1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11-20, -30, -40		
Row 3	$U(0.50–0.90)$		**Para.**	**10.35**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**1**
		PC		10.05	1.013	0.883	<0.883									2
	n=20	P-Axis		9.61	0.457	<0.457									Reduced-Corr	2
	N=1000	ML-SMC	UW	9.59												
			W	26.85	0.751	<0.751									Reduced-Corr	>1 χ^2=1523.8*
Row 8	$U(0.30–0.90)$		**Para.**	**8.16**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**1**
		PC		8.10	1.188	1.141	<1.00									3
	n=20	P-Axis		7.65	0.638	<0.638									Reduced-Corr	3
	N=1000	ML-SMC	UW	7.60												
			W	21.42	0.705	<0.705									Reduced-Corr	>1 χ^2=1322.8*
Row 13	$U(0.05–0.95)$		**Para.**	**6.81**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**1**
		PC		6.88	1.267	1.183	1.17	1.07	<1.00							5
	n=20	P-Axis		6.48	0.626	<0.626									Reduced-Corr	5
	N=1000	ML-SMC	UW	6.42												
			W	24.00	0.649	<0.649									Reduced-Corr	>1 χ^2=1345.5*
Row 18	$U(0.05–0.95)$		**Para.**	**9.98**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**1**
		PC		10.23	1.39	1.35	1.29	1.17	1.11	1.11	1.03	<1.00				8
	n=30	P-Axis		9.87	0.99	<0.994									Reduced-Corr	8
	N=1000	ML-SMC	UW	9.78												
			W	32.03	1.06	<1.00									Reduced-Corr	>1 χ^2=3720.7*
Row 23	$U(0.05–0.95)$		**Para.**	**12.88**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**1**
		PC		12.92	1.27	1.23	1.20	1.15	1.13	1.10	1.08	1.05	1.04	<1.00		10
	n=40	P-Axis		12.52	0.78	<0.78									Reduced-Corr	10
	N=1000	ML-SMC	UW	12.45												
			W	37.29	1.20	<1.00									Reduced-Corr	>1 χ^2=6438.3*

*: significant at 5% level.

because more than one significant factor was retained -- regardless of the test length or range of the ρ'_g. In addition, it was observed that the number of retained factors increased as either the test length increased or as the range of the ρ'_g expanded. In terms of size of the first eigenvalue (column 5), the three methods performed equally well in that they all yielded values close to the parameter values of the baseline reference-- again, regardless of the test length or the range of ρ'_g.

Concerning the eigenvalue patterns associated with each of the five tetra-corr matrices, the PA method performed much better than did its PC and ML counterparts-- that is, the eigenvalue pattern extracted via the PA method was much more similar to the baseline reference. The magnitudes of all the other eigenvalues were less than 1.00, regardless of the test length or range of ρ'_g. It should be noted that the resulting eigenvalue patterns were extracted from reduced correlation matrices.

4. Methods Based on Homogeneity

Homogeneity measures from domain sampling theory (Nunnally, 1978) place primary emphasis on internal structure-- the relationships among items which comprise a test. The basic formula for deriving an index of homogeneity is: $\rho_{ii} = \dfrac{n\overline{\rho}_{ij}}{1+(n-1)\overline{\rho}_{ij}}$, where $\overline{\rho}_{ij}$ is the is the average of inter-item correlations. This formula states that when n items tend to measure a single trait (common core), the average inter-item correlation is high, and the test is, therefore, more homogeneous. Coefficient alpha (α), one of the most important deductions from domain sampling theory, is another homogeneity measure-- one taking the form

$$\alpha = \frac{n}{n-1}\left[1 - \frac{\Sigma_i^n \sigma_i^2}{\sigma_X^2}\right],$$

$$\text{where} \begin{cases} \sigma_i^2 = \text{item score variance} \\ \sigma_X^2 = \text{test score variance} \end{cases}.$$

The present study used both average inter-item correlation and coefficient alpha to examine the degree to which a unidimensional item set reflects a homogeneous item set.

Table 4 lists population and sample averages of inter-item correlations $\overline{\rho}_{ij}$ and r_{ij}^{tetra}, and $\hat{\alpha}$ for the five tests. r_{ij}^{tetra} was calculated based on a tetra-corr matrix of n by n, and $\hat{\alpha}$ was obtained from a U-data matrix of N by n.

As shown in Table 4, the population averages of the inter-item correlations ($\overline{\rho}_{ij}$) were 0.503, 0.377, 0.269, 0.263, and 0.250 for the five test sets. A comparison of $\overline{\rho}_{ij}$ values reveals that the inter-item correlation averages were dependent on the ρ'_g range but not on the length. The same pattern held true for the sample statistic, r_{ij}^{tetra}. This result can be explained by the fact that the two highest values of either $\overline{\rho}_{ij}$ or r_{ij}^{tetra} were associated with a test length of 20, from which ρ'_g fell on the 0.50-0.90 and 0.30-0.90 interval, while the three lowest values were associated with test lengths of 20, 30, and 40-- all with ρ'_g falling on the 0.05-0.95 interval.

As shown in Table 4, the observed $\hat{\alpha}$ values for the five tests were 0.829, 0.784, 0.727, 0.801, and 0.833. The first three values indicate that when the test length was fixed at 20, $\hat{\alpha}$ was a function of the range of ρ'_g. The last three values indicate that when the ρ'_g range was fixed at an interval of 0.05-0.95, $\hat{\alpha}$ was a function of test length. $\hat{\alpha}$ was, therefore, a function of both test length and ρ'_g. In addition, these results show that a $\hat{\alpha}$ value higher than 0.80 could depend on where ρ'_g fell along the interval of 0.50-0.90 or 0.05-0.95. This means that a unidimensional data set could contain less homogeneous items since their common factor loadings could be less than 0.30.

5. Conclusions and Suggestions

This study reviewed the performance of unidimensionality measures under a variety of simulated data sets which were in compliance with the sufficient conditions for the two-parameter normal ogive model. The study design was similar to that of a Type I error study. The unidimensionality measures investigated were based on homogeneity, factor analysis, the item fit statistic, and Stout's DIMTEST methodology. The simulated data sets varied in terms of the range of item-ability correlations (ρ'_g) and of test length.

The two unidimensionality measures based on homogeneity theory (domain sampling theory) were the average inter-item correlation (r_{ij}^{tetra}) and coefficient alpha ($\hat{\alpha}$). Results showed that the average inter-item correlation was a function of the range of ρ'_g (the item-ability correlation) but was independent of the test length (n); coefficient alpha was found to be a function of both the range of ρ'_g and test length. However, given a fixed test length, both measures increased as ρ'_g increased. Therefore, the average inter-item correlation may be regarded as a better unidimensionality measure compared to coefficient alpha. In addition, it was observed that a unidimensional set of test items did not necessarily represent

Table 4. Population Averages of Inter-item Correlations and Corresponding Sample Statistics $\overline{r_{ij}^{tetra}}$, Along with Alpha Values for the Five Tests

	n=20 $\rho_g' \approx U(0.50\text{–}0.90)$	n=20 $\rho_g' \approx U(0.30\text{–}0.90)$	n=20 $\rho_g' \approx U(0.05\text{–}0.95)$	n=30 $\rho_g' \approx U(0.05\text{–}0.95)$	n=40 $\rho_g' \approx U(0.05\text{–}0.95)$
Para.	$\overline{\rho_{ij}}$=0.503	$\overline{\rho_{ij}}$=0.377	$\overline{\rho_{ij}}$=0.269	$\overline{\rho_{ij}}$=0.263	$\overline{\rho_{ij}}$=0.250
Statis.	$\overline{r_{ij}^{tetra}}$=0.463	$\overline{r_{ij}^{tetra}}$=0.344	$\overline{r_{ij}^{tetra}}$=0.247	$\overline{r_{ij}^{tetra}}$=0.255	$\overline{r_{ij}^{tetra}}$=0.242
	$\hat{\alpha}$=0.829	$\hat{\alpha}$=0.784	$\hat{\alpha}$=0.727	$\hat{\alpha}$=0.801	$\hat{\alpha}$=0.833
	N=1000	N=1000	N=1000	N=1000	N=2000

a homogeneous set since the items' first factor loadings could be less than the criterion value of 0.30.

Three factor analysis methods -- principal component, principal axis, and maximum likelihood — were used to examine unidimensionality. Differences were found in the relative performance associated with the three methods according to the type of correlation analyzed and the parameter examined. When analyzing the tetra-corr matrix, the principal axis method performed much better than did the other two with respect to holding an eigenvalue pattern similar to that expected under $H_0{:}d=1$, regardless of the test length or range of ρ_g'. In terms of the first eigenvalue, the three methods performed equally well, with each one producing a value close to its parameter counterpart. In terms of the number of extracted factors, all three methods failed to display a one-common factor pattern because more than one significant factor was retained.

The two unidimensionality measures based on item fit statistic were the likelihood ratio chi-square statistic and root mean square standardized residual. The performance of the likelihood ratio chi-square statistic in examining item goodness-of-fit was found to be sensitive to test length. For example, when the test length $n \geq 20$, the statistic tended to mistakenly flag items as poor-fitting in proportion to test length. However, when those poor-fitting items underwent a second- stage examination via the root mean square standardized residual, none of the items showed a significant residual value -- indicating an absence of problems in terms of goodness-of-fit.

It was found that the validity of Stout's DIMTEST statistic ($T = \frac{T_L - T_B}{\sqrt{2}}$) with respect to the type I error depended on the method used to select AT1 M items for the T_L statistic. The present study found that when AT1 M items were chosen via the DIMTEST factor procedure, the calculated T statistic values supported H_0:d=1; however, when the M items were selected by means of a prior knowledge procedure, the calculated T statistic values rejected H_0:d=1. These results held true regardless of the test length or range of ρ_g'. Furthermore, it was found that both selection procedures yielded M item sets which differed in the degree of homogeneity. For example, M items selected by the DIMTEST factor analytical procedure were, on average, less homogeneous than their counterparts selected by the prior knowledge procedure. The results of this study suggest that Stout's DIMTEST statistic might be invalid in situations where AT1 M items are extremely homogeneous relative to the remaining n-M test items.

Based on the overall results of this empirical review, the following suggestions are offered regarding the use of unidimensionality measures based on different approaches. To arrive at an unidimensional and homogenous item set, the average inter-item correlation index functions better than coefficient alpha does. To determine whether a data set satisfies an assumption of undimensionality in terms of a one-common factor model, principal axis methodology is the clear choice for examining extracted eigenvalue patterns based on a tetrachoric correlation matrix. If the primary concern is whether or not test items hold essential local independence, Stout's DIMTEST factor procedure is preferred not only to the prior knowledge procedure, but also to the other unidimensionality measures. For assessing whether individual items fit the two-parameter normal ogive model, a two-stage goodness-of-fit procedure which entails both the chi-square statistic and root mean square standardized residual may be used when $n \geq 20$. Here, it should be noted that all of the above suggestions are valid when the group of examinees tested has approximately normal distribution of ability.

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驗證評論 IRT 單維檢定法

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摘　要

本文先行摘述研究單維檢視法優缺點，繼而就文獻尚未顧及的層面評估單維檢視法判斷試題單維的正確性。本文研究設計擬似探討第一類型誤差，亦即就符合二參數常態肩形曲線的模擬資料比較單維檢視法的效度。本文所使用的資料涵蓋不同的試題與能力相關的範圍及測驗長度，而所評估的單維檢視法來自因素分析理論，領域抽樣理論，Stout 氏基本單維論，以及試題適合度考驗法。

依據研究發現，本文建議使用單維檢視法考量原則如下：1) 就領域抽樣理論而言，若欲選一組試題滿足單維及高同質性，則試題相關平均指標優於 alpha 係數；2) 就斯皮爾曼單一共同因素理論之單維定義而言，主軸分析法優於主成份分析及最大概法，因其所抽取因素特徵值類型近似母群參數類型；3) 若由試題滿足最基本單維數考量，則 Stout 氏的 DIMTEST 併隨因素選題法優於先驗選題法及其他單維檢視法；4) 若欲檢視個別試題符合二參數常態肩形曲線符合的程度，當題數大於或等於 20，可先後以 χ^2 統計量及標準化殘餘值進行二階段檢視程序。

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Development of A Grade Eight Taiwanese Physical Science Teacher's Pedagogical Content Knowledge Development

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Abstract

The purposes of this study were to examine a beginning Taiwanese female science teacher's physical science teaching, and how her science teaching developed from her senior year to her first semester of classroom teaching. Both microscopic and macroscopic pedagogical content knowledge (PCK) were implemented in the investigation. A qualitative research method was applied. The research was conducted from Shu-May's senior year to the first semester of her beginning year. The findings revealed that the nature of Shu-May's PCK consisted of instructional strategies and representation. Her instructional strategies were characterized by the verification method of introducing science concepts. Her instructional representation included linguistic expressions, calculation problems, demonstration, daily-life experiences and relevant examples via verbal and visual display. Shu-May's PCK development revealed integration, relevance, and specificity features. Shu-May's knowledge of her students changed from a general view of student learning to a more specific understanding of their content learning ability. Her content knowledge also changed from a general view of the physical science discipline to specific knowledge of what students should know about each topic. Factors influencing Shu-May's PCK development were her perceptions of science teaching and students' science learning, her insensitivity in both judging students' level of understanding and deciding on appropriate goals for the lessons, her declining retention of pedagogical knowledge learned in teacher education programs, and the different cultural norms she perceived in different teaching contexts.

Key Words: pedagogical content knowledge, beginning science teachers, teacher's professional development, physical sciences, junior high schools

I. Introduction

Teachers play a key role in influencing students' science learning. Science teacher education also plays a crucial role in educating science teachers to be competent and capable of integrating content and pedagogical knowledge in classroom teaching. During the past decade, research on science teacher education has gained more attention than before. Reforms in science teacher education programs have progressed in many states in the U.S. (Brunkhorst, Brunkhorst, Yager, Apple, & Andrews, 1993; Gilbert, 1994; Tippins, Nichols, & Tobin, 1993).

In Taiwan, a decentralized teacher education system was approved by legislators; teacher education is now in a transition stage. Both normal universities and general universities can offer science teacher education programs. In normal universities, science teacher education programs are located within science departments. When students pass the entrance examinations and enroll in the science departments, they need to take both content and education courses together for four years; practice teaching in a junior high school requires an additional year. Therefore, students enrolled in normal university program take five years to become a teacher. In other general universities, students enrolled in a chemistry department need to take additional education courses offered by a teacher education program to become a teacher. Once they receive a diploma they need to find a high school in which to have a year-long practice teaching experience.

The new legislation in teacher education raises a lot of research issues, including developing an assessment system for evaluating science teachers and developing appropriate educational programs for science teacher education. Although there are many ways to improve science teacher education, Finley, Lawrenz, & Heller (1992) indicated that carefully examining the impact of science teacher education on beginning teachers' professional development was crucial in designing future teacher education programs.

Presumably, a teacher needs to have content knowledge and know how to teach in order to be a competent teacher. In other words, to be competent, teachers need to both possess and integrate content and pedagogy knowledge. However, few researchers have investigated the above assumption until the last decade. Science educators (Gess-Newsome & Lederman, 1993; Hashweh, 1987; Hoz, Tomer, & Tamir, 1990; Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995) started to investigate the importance of both pre- and in-service science teachers' content and pedagogy knowledge and the way the knowledge was integrated in teachers' thinking and acting. Shulman's (1986, 1987) concept of PCK, which addressed the teachability of content knowledge, is another direction in investigating the integration of teachers' content and pedagogy knowledge.

Besides revealing the nature of how teachers' integrated content and pedagogy knowledge in thinking and acting influenced their teaching, teacher educators also expected to unravel the underlying process of teachers' professional development from the university through their field experiences. There are several models of teacher professional development including those of Fuller & Brown (1975), Berliner (1988), and Kagan (1992).

Fuller & Brown (1975) identified the process of a teacher's professional development from the survival stage to the impact stage. In other words, a teacher's concern passes from concerns about one's own adequacy to the teaching task and finally to his/her effect on students.

Applying both schema theory and cognitive science, Berliner(1988) constructed a five stage process of a teacher's professional development. It includes: novice, advanced beginner, competent, proficient, and expert stage. In the novice stage, a teacher's teaching performance is based on his/her rationale, which is inflexible and requires purposeful concentration. In the advanced beginning stage, a teacher learns strategic knowledge and becomes flexible in following rules in the classroom. In the competent stage, a teacher is able to choose a course of action, prioritize things and make plans. In the proficient stage, a teacher is able to pick up information from the classroom without conscious effort and is able to predict classroom events. In the expert stage, a teacher's performance is fluid and seemingly effortless. He or she uses standardized, automated routines in handling instructions and management. Berliner thought most beginning teachers were in the novice stage, and many second and third year teachers were in the advanced beginner stage.

Kagan (1992) categorized a teacher's professional development into five components: an increase in metacognition, an increase in knowledge about students, a shift in attention from self to students, development of standard procedures, and, finally, growth in problem solving ability. In Kagan's model, there was no specific indication that years of teaching experience were related to the developmental stages.

These authors provided some general ideas about how teachers may develop their teaching competence. However, they did not address how beginning teachers integrated what they had learned from content and pedagogy courses into their content teaching presentations, or how they develop their content teaching in the field, that is their PCK development. Future research needs to investigate specifically how beginning science teachers' develop their content teaching in a natural setting, and try to trace back the impact or lack of impact of science teacher education programs on their content teaching development. Only by this kind of examination can we know how to improve our future science teacher education in a more meaningful way for preservice science teachers.

Previous research on PCK includes: examining the nature and substance of teachers' PCK in mathematics and science teaching (Marks, 1990; Tuan, 1996a); investigating the knowledge beginning science teachers need to teach a particular science topic (Geddis, 1993; Geddis, Onslow, Beynon, & Oesch, 1993); exploring the development of pre-service science teachers' subject-matter knowledge, pedagogical knowledge, and PCK development (Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995; Tuan, 1996b); illustrating methods to facilitate science teachers' PCK (Barnette, 1991; Clermont, Krajcik, & Borko, 1993; Dana & Dana, 1996; Klienfeld, 1992; Ormrod & Cole, 1996); and comparing the differences of the PCK between novice and experienced science teachers (Clermont, Borko, & Krajcik, 1994; De Jong, 1997). The above studies used different definitions to describe PCK, thus influencing their research approach.

Tuan(1996c) reviewed research on PCK and concluded that research done on PCK revealed two views. The microscopic view has been emphasized by researchers like Shulman (1986, 1987), Kennedy (1990), McDiarmind, Ball, & Anderson (1989). These researchers have emphasized how teachers represent their understanding of a particular content topic to a particular classroom students' understanding level. The macroscopic view of PCK has been emphasized by research by Cochran, DeRuiter, & King (1993), who have treated PCK as the overlap of several domains of knowledge learned in the teacher education program, such as curriculum knowledge, pedagogical knowledge, subject matter knowledge, knowledge of students, and knowledge of context, and how these translated into thoughts and actions in classroom teaching. The more integration of the above domains of knowledge into the teachers' thoughts and actions in classroom teaching, the more their PCK developed. The difference between the microscopic and macroscopic views of PCK is that the former addresses a particular content topic while the latter addresses a broader base of content teaching across different topics. Tuan(1996c) also suggested that future studies done on this area should define the concept of PCK.

Researchers have reviewed a few studies on how pre-service/ beginning science teachers developed their PCK (Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995; Tuan, 1996b; Yang & Wu, 1996). These investigations either addressed the macroscopic view of PCK development (Gess-Newsome & Lederman, 1993; Lederman & Latz, 1995; Lederman, Gess-Newsome & Latz, 1994), or used the microscopic view to look at the PCK development of preservice teachers (Tuan, 1996a) or beginning biology teachers (Yang & Wu, 1996). None of the studies identified traced the development of a physical science teacher's PCK from one's senior year to the first year of teaching, or investigated the development of a teacher's macroscopic and microscopic view of PCK.

Based on the above reasons, the purposes of this study were to examine the characteristics of a beginning Taiwanese female science teacher's junior high school physical science teaching, how her science teaching developed naturally from her senior year to her first semester of classroom teaching, and examine the factors influencing the development of her PCK. Both microscopic and macroscopic levels of PCK were implemented in the investigation. Findings from this study should help science teacher educators not only gain more understanding about the nature of beginning science teachers' PCK, and how this knowledge changes during the first semester of teaching, but also help science teacher educators develop better science teacher education programs in the future.

II. Design and Procedure

1. Description of Science Teacher Education Program

This study was done in a normal university located in the middle of Taiwan. As mentioned before, preservice teachers enrolled in the chemistry department of the normal university have to take chemistry and education courses in the same department with the same classmates. Pedagogy courses offered in the chemistry department included foundations of education, secondary education, educational psychology, science education, instructional materials and chemistry teaching methods, and a practicum course. Courses that integrated content and pedagogy were chemistry teaching methods courses and practicum courses. After finishing their course work in the fourth year, preservice teachers have a year-long internship experience in a junior high school to practice teach, obtain a teaching certificate and receive a graduation diploma. Beginning teachers in their fifth year are graded and supervised by junior high school principals and college professors; however, in reality, they are doing the same work as professional teachers and seldom ask their supervisors for help.

2. Description of Instructional Materials and Teaching Methods Course and Practicum Course

The first author offered two courses for the chemistry department, a chemistry teaching methods course and a practicum course. In the chemistry teaching methods course, the first author covered teaching strategies, such as lab teaching, conceptual teaching, discrepant event teaching, the learning cycle and creative science teaching. The aims of the course were to increase the preservice teachers' appreciation and teaching repertoire of different science teaching strategies. Instructional methods used for this course included introducing new methods, demonstration, group discussion, role playing, group presentation, and whole class discussion. Basically, the author was a role model using the above strategies in the class and then conducted group discussions to help preservice teachers discuss what they thought of the teaching methods.

Practicum courses were offered for two semesters. For the first semester, preservice teachers practiced microteaching twice on the topic they had chosen; in the second semester, they had a one-month practicum in a junior high school. Instructional methods used in the practicum course mainly focused on reflective teaching (Schön, 1986). The author applied many methods such as journal writing, self analysis of one's own teaching and reflection on other classmates' suggestion to increase the preservice teachers' reflective ability on their teaching. The author also applied peer coaching to supplement their reflective teaching experience. Each preservice teacher was asked to choose their own peer coach. They then helped one another with lesson plans and gave feedback on each other's performance. After finishing each microteaching lesson, each preservice teacher needed to analyze one's own teaching, and also respond to the feedback from their classmates and peer coach. During their one month field experience, each preservice teacher needed to make a journal of their classroom teaching experience. After they came back from school, the author covered topics related to classroom management, science fairs, and teachers' professional development.

3. Context of the Junior high School

The junior high school where Shu-May taught was located in a rural county in central Taiwan, with farmers or blue-collar workers constituting the majority of the population. Thus, most of the students' parents did not have high expectations for their children's achievement. The learning environment in this school was more casual without the competitiveness of city schools. The class observed was an eighth grade physical science class of 45 "ordinary" students. An ordinary class in that school meant that the students' achievements were lower than the A class students. The school selected higher G.P.A. students from among the same grade level and put them into the A class in order to prepare them for passing the senior high school entrance examination. The other students were put into ordinary classes where probably none of the students would pass the senior high school entrance examination nor be able to enter public professional schools after their graduation.

4. Data Collection

Based on the nature of this study, a qualitative research method (Bogdan & Biklen, 1992) was applied. A beginning Taiwanese female science teacher, Shu-May, was involved in the study for many reasons: (1) she took the first author's chemistry teaching methods and practicum course in her senior year of college; (2) the researchers had collected teaching performance data in her senior year in the program; (3) the location of Shu-May's school was close to the university, enabling intensive classroom observation; (4) among her classmates, her G.P.A. was in the average range; and (5) she was willing to participate in the study.

A. Data Collection in the First Year

Data collection in Shu-May's senior year included two micro-teaching video-tapes of about 20 minutes each, one hour of real classroom teaching videotape, her lesson plans for the microteaching experience, and other assignments for chemistry teaching methods and practicum courses. These data were mainly collected by the first author, who was also her instructor for both the chemistry teaching methods and practicum courses. The second author had one year of junior high school teaching experience and two years of science education graduate courses. He was Shu-May's friend in college, played the role of an-observer-as-participant (Gold, 1958), and collected data on Shu-May's first year of teaching.

B. Data Collection in the Second Year

In the second year, data collection included a twice weekly classroom observation for one semester, interviews with Shu-May before and after her classroom teaching, and a collection of Shu-May's written documents such as her lesson plans, notes and students' tests. Formal interviews were conducted before, during, and at the end of the semester and addressed Shu-May's perceptions of junior high school physical science teaching, her chemistry knowledge and pedagogical knowledge (see appendix I). Informal interviews conducted before and after each classroom observation focused on Shu-May's plans for the topic she was going to teach, her knowledge of the topic she was teaching, the references she used in her teaching, and her reflection on her teaching. Researchers also interviewed Shu-May on the reactions collected from students. Document collection included her lesson plans, tests and students' test results during her first year of teaching.

5. Data Analysis

Data analysis was based upon the open-coding method (Bogdan & Biklen, 1992). The second author first analyzed all the interview transcripts and classroom observation field notes, and then generated an open coding system. The two researchers examined the raw data such as interview transcripts and videotapes of Shu-May's classroom teaching together in order to elaborate on the coding systems. The first author played a critical role in analyzing the raw data and reading the temporary findings written by the second author. She then evaluated these tentative results and suggested that the second author find more evidence to support or reject the findings until the authors reached a consensus. The peer debriefing procedure (Lincoln & Guba, 1985) was used in the data analysis to increase the trustworthiness of the findings.

Miles & Huberman (1994) suggested using tables to present qualitative findings, and a table was generated listing the frequency of Shu-May's teaching activities (Table 1). Together the researchers analyzed the beginning of three video tapes of Shu-May's teaching to count the frequency of her teaching strategies in order to gain consensus on the attribute and frequency of each teaching strategy. The second author analyzed the rest of the video-tapes of Shu-May's teaching performance. The definitions of each of her teaching activities are listed in Table 2.

The purpose of the study was to look at how the beginning teacher integrated content, pedagogy, and students together in thought and performance on her content teaching in a natural setting. Thus, teaching activities (Table 1, 2) were analyzed but the appropriate level of Shu-May's teaching performance was not. Another part of the data analysis that needs to be considered was that, based on the nature of the topics, each topic could accommodate different teaching approaches based on the content. For instance, an element and a compound can be introduced by using the history of science approach; for the water and air topic, the teacher could first use daily-life experiences for students to appreciate the importance of water and air, and then discuss the property of these matter. However, when we examined Shu-May's teaching, her teaching strategies were almost the same when covering different topics. Thus, we coded her teaching into different teaching activities (Table 2) and then examined how Shu-May organized these teaching activities, which were her teaching strategies, across topics. The third important issue that needs to be addressed is that during her fifth year Shu-May relied on her mental thinking when planning instead of actually writing down everything she needed to cover in the class. In addition, in responding to the authors, her thinking about teaching was to mention in general, some teaching tasks, such as lecture, demonstration, and problem solving. Thus, the authors could hardly analyze Shu-May's planning in terms of frequencies and level appropriateness of the representations listed in Table 1 & 2. Therefore, our data analysis relied on her verbal descriptions of teaching and actual observation of her classroom performance.

Lincoln & Guba (1985) listed four criteria for maintaining the trustworthiness of qualitative research findings. These are credibility, transferability, dependability, and confirmability. In this study, the two researchers knew Shu-May and had worked with her from her senior year to her first year of teaching. The second author stayed in the field for half a year, providing an opportunity for the researchers to collect Shu-May's PCK and to clarify the researchers' understanding. This prolonged engagement should help to increase the credibility of the findings. Triangulation methods (Bogdan & Biklen, 1992) were also applied in the data collection and analysis procedures, such as collecting data from different sources and including different researchers in the analysis of the findings. Finally, the study provided the following: detailed data analysis procedures, Shu-May's views of the research findings, comparisons between our findings and previous research, detailed information on the research context and the roles of the researchers. These methods were incorporated to increase the trustworthiness of the findings.

III. Findings

1. The Development of Shu-May's pedagogical content knowledge

A. The main organization of Shu-May's science teaching strategies did not change throughout the study; she used a verification method to teach science concepts listed in the textbook from the beginning to the end of the study. Toward the end of the study, Shu-May used more teaching strategies to help students memorize science concepts.

Analysis of Shu-May's teaching from her senior year to first year of teaching showed that her teaching activities(Table 1, 2) and ways of organizing these teaching activities were very similar to other preservice Taiwanese chemistry teachers (Tuan, 1996a). These teachers' content teaching were characterized as the verification way to teach science.

Shu-May had an opportunity to practice ideas introduced in the methods course in her microteaching experience during her senior year. However, she

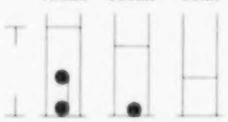
Table 1. Shu-May's Teaching Activities for Each Topic

Classroom Teaching Activity	Frequency						
	Topic Taught in Senior Year			Topics Taught in the First Half Year of Teaching			
	Microteaching Lessons		Field Experience Lessons	Measurement & Units of Metric (300 min)*	Water & Air (150 min)*	Influence of Heat Matter (200 min)*	Elements & Compounds (250 min)*
	Linear Movement in Velocity (27 min)*	Elements with Similar Properties (29 min)*	Property of Halogen (50 min)*				
1. classroom management			1	32	17	12	17
2. review previous concepts	1	1	2	10	6	8	14
3. introduce formulas	2		1	5	4	4	5
4. ask for memorization			1	7	10	7	12
5. underlining important parts in textbooks and/or taking notes			2	12	13	16	21
6. emphasize the content which would be convered on test			1	9	3	5	6
7. using added scores to encourage Ss				2			
8. ask open-ended questions	3	4	5	9	4	8	
9. ask individuals to respond	2	1		6	4		
10. provide opportunities for Ss to discuss	2	1		4	5		2
11. quiz					2	1	
12. explain science concepts	4	6	29	11	26	28	
13. summarize introduced concepts	3	8	17	4	20	15	
14. demonstrats problem solving	3			11	2	10	3
15. students do problem solving exercises	1			4	2		
16. provide daily life examples				34	17	20	2
17. use analogies to explain concepts	2	1		1	1	1	3
18. use illustration to explain concepts		4		1	16	7	10
19. use graps to facilitate problem solving	2			3	1	2	
20. demonstrate concepts using real objects	1	2	1	1	3	1	
21. demonstrate lab activities			1	2	3	1	1
22. Ss conduct lab activities		1	1	4			

* Length of teaching time

thought the best way to present the velocity topic was a "traditional lecture." The strategies she used in introducing velocity were to introduce the key concepts at the beginning of the lesson, review the previous lessons in order to connect previous concepts to this topic, define velocity, provide problem solving techniques for both demonstrations and exercises for students to appreciate aspects of velocity, illustrate the difference between velocity and speed, derive a velocity formula, and summarize concepts. In her twenty-seven-minute microteaching experience, Shu-May's major emphasis was on ex-

Table 2. Example of Each Teaching Activity

Teaching Activities	Examples
1. Classroom management	T: Lin-Pin, do not talk in class, pay attention.
2. Review previous concepts	T: Last period we studied page 34,Density. Density = Mass /volume
3. Introduce formulas	T: Today I will introduce pressure, pressure = Direct force/area.
4. Ask Ss to memorize	T: The definition of the law of constant composition, the mass of all elements in a compound, has a certain ratio. This is very important, memorize it.
5. Ask Ss to underline important points or take notes	T: Look at page 161, the third line, the law of constant composition, all elements combine into compounds, their mass have the same ratio, this is very important, underline this paragraph.
6. Address the content which would be covered on test	T: "The law of constant composition is very important, it will be on the test."
7. Apply additional score to encourage students	T: If you answer this question correctly, I will add three points to your average score.
8. Ask open-ended questions	T: How to separate sugar and iron powder ?
9. Ask individual students to respond	T: Ah-Lin, density equals what divided by what?
10. provide opportunity for student discussion	After asking questions, Shu-May gave time for students to conduct discussion.
11. Quiz	After covering the content in the class, Shu-May asked the students to take out a piece of paper and pen to take a quiz. She then wrote down a question on the board: There is a fish tank on a square table. The table weights 1200g. The fish tank weighs 400g. Each side of the table is 10 cm in length. (1) What is the direct force? (2) What is the total contact area? (3) What is the pressure ?
12. Explain and introduce concepts from textbook	T: Let me introduce a term. The vertical direction of the force on the object, we called the vertical force...How is the vertical force related to pressure? SS: Direct proportion.
13. Summarize introduce lab finding and concepts	After explaining science concepts, Shu-May would summarize what she had just taught to the students on the blackboard. For instance, after introducing pressure, she then wrote down the following notes on the blackboard. P (pressure) = F (vertical force) gw kgw / A (area) cm^2 m^2
14. Demonstrate problem solving	T: look at page 45, there are two bricks. How much does each brick weigh? SS: 2000g T: How about the length of the brick? (She wrote on the blackboard) SS: 20 cm T: How about the width of the brick ? SS: 10 cm. T: How about the height of the brick ? SS: 5 cm. [Wrote the following notes on the blackboard] F=2000g Length 20 cm, width 10 cm, height 5cm T: Look at the brick lying on the table. What is it's pressure on the table? Does it relate to vertical force divided by area? How much is the vertical force? SS: 2000g T: How much is area? SS:200 cm^2 T: Length times weight is 20 times 10 equals 200 [Wrote the following notes on the blackboard] $\frac{2000}{20\times10} = (10\ g / cm^2)$
15. Let students do problem solving exercise	Shu-may wrote problem on the blackboard and asked the students to do the problem solving exercise in the class.
16. Provide daily life examples	After introducing how heat influenced matter, Shu-May talked about how water at 4 °C influences the ecology. T: How can fish live in a lake covered with ice on the surface ? T: Because at 4 °C, water has the largest density.. Thus, let's compare 4 °C water and ice. Which one is on the top; which one is at the bottom? SS: 4 °C, water is on the bottom. T: So even if the lake is covered with ice, underneath the ice is the 4°C water; thus, the fish can stay alive.
17.Use analogies to explain concepts	T: The diffusion rate of Hydrochloride and ammonium is like a fat guy and a skinny guy racing. Generally speaking, the skinny guy runs faster than the fat guy. It is the same with the diffusion rate of gas. The lighter gas diffuses faster than the heavier one.
18. Use illustration to explain concepts	T: Chemical reaction is the rearrangement of atoms, such as carbon and oxygen combusting into carbon dioxide. The solid dot represent carbon. The hollow dots represent oxygen. $C + O_2 \rightarrow CO_2$ ● ○○ ○●○
19. use graph to facilitate problem solving	When Shu-May asked ss how to measure the volume of Pine-Pong balls, she drew a graph on the board and explained to ss how to do it. 
20. Demonstrate concepts using real object	Shu-May used a bottle of water to show ss the relationship between the depth of water and pressure.
21. Demonstrate with lab activities	Shu-May demonstrated lab activities from the textbook
22. Students conduct lab activities	Shu-May invited students to help her conduct lab demonstrations , or she let students do lab work in groups.

plaining science concepts to the students, who were also her classmates.

In Shu-May's first half-year of junior high school teaching, she used a similar teaching pattern in organizing her lessons. The pattern followed a usual sequence: (1) introducing science terminology; (2) using natural phenomena to illustrate science terminology; (3) explaining the definition of science concepts, principles, and/or formulas; (4) providing examples to re-emphasize concepts, principles and/or formulas; (5) providing problem solving exercises to help students understand previous concepts; and (6) using quizzes to evaluate students' understanding. In general, Shu-May's teaching activities were mainly organized to focus on introducing science concepts to students, and to help students memorize the concepts in order to be successful in taking school examinations.

The literature of PCK has indicated (Geddis, 1993; Shulman, 1986) that using conceptual change teaching methods to overcome students' misconceptions is one important feature of PCK. This characteristic was not found in Shu-May's science teaching from her senior year to the first year of teaching. Shu-May's way of organizing instructional strategies throughout the study were characterized as using a verification method to organize science concepts for students. Shu-May did make some changes in her instructional strategies at the end of the study; these were: (1) increasing some representations to help students appreciate science concepts; (2) increasing the frequency of helping students to memorize science concepts, such as underlining the important concepts and focusing on the possibility of the concepts on tests; and (3) practicing problem solving techniques (Table 1). These strategies were to help students get good grades on school tests.

B. Although toward the end of the study, Shu-May increased her use of various representations, such as providing daily life examples and using illustrations to represent science concepts, her major representations still relied on both linguistic expression and calculation problems.

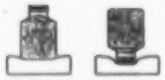
Many researchers(McDiarmind, Ball, & Anderson, 1989; Shulman,1986) have indicated that PCK includes how a teacher represents content to a student's level of understanding. In Shu-May's senior year, she chose two topics for microteaching teaching experiences; one was on the velocity of linear movement and the other was elements with similar properties. For velocity, she spent the majority of her time in explaining the definition of velocity, deriving the formula for velocity, and using problem solving to help students appreciate and remember the concepts she had just taught. In the second microteaching experience, Shu-May introduced important concepts related to "how to categorize the metal elements," reviewed the previous lessons in order to remind students of the properties of the Alkali metal group and Alkaline earth metal group, and introduced the elements by showing and introducing each element to students. After that, she drew the same table listed in the textbook on the board (the purpose of the table was to help students to see the differences in appearance and properties of elements before and after chemical reactions), reminded students of lab safety and some important procedures, demonstrated the first two procedures, and then divided students into three groups to conduct the lab activities. At the end of the lab, Shu-May summarized the students' lab results (Table 1). These teaching representations were very traditional and mainly relied on Shu-May's linguistic expressions.

In her junior high school teaching, she liked to use linguistic expressions, problem solving, demonstration, daily life examples and relevant examples by verbal or visual displays to help students quickly comprehend and then memorize and apply physical science concepts.

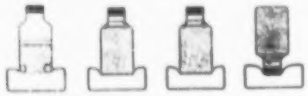
Shu-May liked to use visual displays, either by drawing or showing concrete objects to motivate students in learning new terminology and in appreciating the substance of abstract concepts. Figure 1 shows how Shu-May used drawings to express concepts related to pressure by drawing on the blackboard four bottles laying on a sponge.

> T: The first bottle contains less water, the second, third and fourth bottles are all filled with water, but the fourth one is upside down on the sponge. Compare the depression level of the sponge.

Shu-May used concrete objects to help students appreciate concepts. For example, Shu-May brought a plastic bottle filled with water, with three holes (stabbed with a sharp-pointed pen) covered with tape on the side of the bottle. She asked the students to predict which holes would let water spurt the furthest(the upper, middle, or bottom hole). She then removed the tape from the holes and let the students see the result, and asked them which factor influenced the water spurt. The students stated depth of the water as the answer, and Shu-May explained that the pressure of water is influenced by the vertical force on the



(Note: These pictures were drawn on the textbook)



(Shu-May drew these pictures on the blackboard)

Fig. 1. The comparison between the picture of pressure in the textbook and in Shu-May's teaching.

side of the bottle.

Shu-May mentioned that the abstractness of concepts was the indicator for her to use a visual display; these visual displays ranged from real objects to symbolic displays, such as diagrams. Shu-May explained her timing in using a visual display:

> If it (abstract concept) could be expressed by a real object that will be great...if they do not understand atom, or molecule, I will draw some pictures on the board, or use Styrofoam balls to build a model to explain abstract concepts. If the concepts can be seen, such as the combustion of chemicals ... I will use real objects to show students the results of combustion. Anyway, if there is a real object that can describe the concepts, I will use the real object to show students.

Besides the above instructional representations, Shu-May would improvise with daily-life examples in her teaching. The purpose of using daily-life examples was to help her students appreciate the substance of the science concepts. Sometimes daily-life examples were used to help students understand the application of the concepts she had just taught. For instance, in introducing "pressure", Shu-May first defined what pressure was, and then she said:

> "if two persons sat on a couch, one a fat guy such as Houng Chin Paou (a famous movie star), and the other is Lee-Pin (a skinny student in the class), will they make the couch sink at the same level, or is there any difference in the sink level between these two people ?" All the students laughed when she used names the students knew.

To Shu-May, these examples were relevant to the students so that they could not only appreciate the concepts but also know how to apply them to a new situation.

In another example, Shu-May used a concrete illustration to verify the students' appreciation of science concepts. She asked the students to use two fingers to press the two ends of a ball point pen and then asked the following questions:

> T: Press the two ends of the ball-point pen. If the ball-point pen holds steady within your two fingers, that means the force from the right and left hand sides are equal. If it falls from between your two fingers, which one has more pressure?
>
> SS: The sharp side of the ball-point pen.
>
> T: The larger the area, the lower the pressure; so what is the relationship between pressure and area?
>
> SS: Inverse ratio.

In summary, during the investigation period, Shu-May increased her use of visual displays and daily-life experiences to help students understand science concepts (Table 1). However, these representations were not the main themes in her teaching. In fact, Shu-May mainly used linguistic expressions in the classroom, such as "Let me introduce some terminology, the vertical direction of a force on an object is called a vertical force" and "Today, I will introduce pressure, Pressure = Direct Force/ Area." The researchers believed these linguistic expressions were too abstract and complicated for students to appreciate and to understand. Shu-May did not use more concrete ways to introduce and develop concepts. Besides linguistic expression, Shu-May would demonstrate problem calculations most of the time in order to show students how to apply the concepts to a calculation situation. In this kind of demonstration she expected students to distinguish and know all the variables involved in the concept, and to know how to apply these concepts to a new problem situation. To Shu-May, problem solving exercises fulfilled two purposes: (1) to help students have a better appreciation for the substance of concepts or principles; (2) to help students apply what they learned to a problem solving situation. For instance, when she taught about sodium, she wrote some information on the blackboard.

Atomic number		
	Atomic number	Electronic number:
	electronic	Proton number:
Na_{23}^{12}	neutral	Atomic number:
		Neutron number:

> T: So if the atomic number is 11, then what is the proton number?
>
> SS: 11
>
> T: The proton number is the same as the atomic number 11. Then how about the electronic number?

SS:11
T: Did I say that sodium has electronic charge? No. So, the electronic and proton number are all the same; that is 11. How about the neutron number...
SS:....
T: What is the atomic weight?
SS:23
T: As I have said before, almost all the mass is in the atomic nucleus, so all the proton number plus the neutron number is the atomic mass number.
T: If the atomic mass is 23 and proton is 11, then what is the neutron number ?
SS: 12 (Fn940113)

These findings were very similar to data reported by Tuan (1996a) in a previous study; three of the pre-service chemistry teachers expressed the dual purposes of using problem solving as did Shu-May. They used problem solving not only to help students apply the principle/formula to problem situations, but also to help students memorize the principle/formula in order to obtain good grades on examinations.

As summarized by Thorley & Stofflett (1996), a teacher's modes of representation for conceptual change teaching may include linguistic expressions, criteria attributes, exemplars, images, analogies or metaphors, kinesthetic or tactile, and other modes of representations. Although Shu-May used some of the representations, such as using daily-life examples and using illustration to represent concepts, her representations were primarily linguistic expressions rather than other representations. These approaches supported her verification way of organizing her instructional strategies.

C. Shu-May's knowledge of students related to both students' science learning characteristic and ability increased, this knowledge influenced her instructional representations and concept emphases and related variables.

During the study period, Shu-May gained knowledge about students' learning. In Shu-May's senior year, her views of how students learned science were focused on memorization and recitation. She thought students needed to use problem solving to become familiar with concepts. In the teacher education program, the educational psychology course had stressed students' cognitive development. In the instructional materials and teaching methods course, the importance of students' learning by doing science and by experiencing concrete objects had been emphasized verbally. However, these emphases did not seem to have much impact on Shu-May. Her views of students' science learning were very general, and they also reflected Shu-May's view of her own science learning. One excerpt illustrated Shu-May's view of students' science learning at the end of her senior year:

> In the beginning [of the semester], they read the textbook as if they were reading a story. Then they used a red pen to underline the important points. After they had underlined the important points, they would try to understand the concepts. When they practiced problem solving, they were fully able to understand what the concepts meant.

After Shu-May interacted with her students, she started to talk more about how the students' arithmetic and Chinese comprehension ability influenced their science learning. For instance, in a calculation situation, Shu-May mentioned the students could only write "density equals mass divided by volume," but did not know how to calculate the equation. But Shu-May treated this problem as a Chinese literacy problem because the students did not understand what the "unit" of mass meant. To her, there was no way to help them understand the problem. She did not recognize that even though the students had memorized the definition of density, since they did not understand the concept, they could not apply the scientific terminology to a new situation. This represented a more fundamental learning problem than what Shu-May considered. A group of students explained to the researchers why they could not learn well in physical science. One student mentioned:

> It (learning physical science) not only requires memorization but also calculation. We are not good at mathematics and cannot solve calculation problems in physics, so we cannot learn physical science well.
> As Shu-May described after the class: I gave them a test on "one meter is equal to how many kilometers." Almost half the class wrote 10km.

Besides being unaware of some of the students' problems in learning new science concepts, Shu-May did not know their previous conceptions or difficulties in learning typical science concepts. Interviews with Shu-May before teaching new topics indicated she did not think of students' preconceptions; she did mention some learning difficulties related to some science concepts. She judged the difficulty level of concepts based on the abstractness of the concepts, such as mole concepts, atom, molecular, etc. However, interviews with Shu-May regarding the teaching strategies she would use to reduce students' learning difficulties, and observations of her teaching, indicated she used few alternative ways to reduce student learning difficulties. What Shu-May used were mainly (1) repetitions, such as using the same analogy (mole is like a dozen of eggs, etc.), or (2) consistently reminding students of the definition of the terminology, such as, "Do you remember I mentioned before, one mole of molecular mass is equal to all the atoms mass in the molecule." Shu-May could have used the students' language and familiar examples or objects to help students comprehend the substance of concepts instead of using repetitious ways.

Shu-May did not really grasp the students' learning difficulties. Only after seeing the students' test results did Shu-May realize their difficulties in learning particular science concepts. Teachers' unfamiliarity with students' preconceptions were also found in studies of other Taiwanese preservice chemistry teachers (Tuan, 1996a) and in U.S. elementary math teachers (Marks, 1990). To Shu-May, the students' literacy (in this case their Chinese language comprehension ability) and arithmetic abilities, and their background in science were more important in influencing them in learning than their preconceptions. She felt they provided the foundation for acquiring new knowledge. In the beginning of the study, Shu-May did not judge whether students would like science and the reasoning behind their science attitudes. Toward the end of the study, Shu-May could explain the students' declining attitude toward science learning instead of just being aware of the phenomena. Shu-May described why the students' attitude toward science decreased dramatically:

> Physical science is difficult. In the beginning of the semester, students liked physical science because of the lab activities. They were willing to listen, watch and memorize science terminology. But! When they faced calculation problems, they totally gave up. (Int 940106-3)

Interviews indicated students responded similarly by indicating "lab is fun" and they were very bad at "problem solving."

Toward the end of the study, Shu-May increased the variety of her concept representations and emphasized their relationships to students.

In the beginning of the study, Shu-May's ideas about the content of a particular topic mainly consisted of several important concepts listed in textbooks. In her senior year, when teaching the unit of constant velocity movement, she described how she would introduce this unit:

> I wrote down four important parts on this topic [in the lesson plan]. First is why we need to learn velocity and the definition of constant velocity movement. Second is the difference between speed and velocity... Third, I will use illustration on S-T and V-T to show students the relationship between position and time, velocity and time, and tell students the difference between these two. (Inv921012)

The observations of Shu-May's microteaching, described in the previous section, were the same as what she said in the above interview. Shu-May tried to help students understand the variables in the concepts using many calculation problems; few representations were used in her microteaching.

Toward the end of the study, Shu-May started to care more about using different content representations and helping students distinguish the difference between the variables of the concepts. For instance, in interviewing Shu-May on her knowledge of pressure:

> Researcher: What do you think this topic (pressure) is about? What is the key point?
> Shu-May: This topic is about the concepts of pressure... I will address this formula (P=F/A), help them appreciate this formula, and explain to the students the relationship between pressure and areas... (Int931007-01)
> Researcher: How would you teach pressure to students?
> Shu-May: [in the textbook], it only described the relationship between pressure and areas, but I think force also needs to be addressed in this topic, so that they can appreciate pressure in relationship to area and force. This organization is better [to show students the whole picture of pressure and the variables related to pressure]. (Int931007-01)

The way Shu-May represented the concepts of pressure are listed in Fig. 1. She drew four pictures on the board instead of the two pictures in the textbook and explained to students how direct force and area influence pressure.

In summary, Shu-May made several changes in her knowledge of students' science learning. In the beginning, she only had general views of students' learning characteristics, and focused on memorization and recitation. Toward the end of the study, her constructed knowledge of students' science learning ability became more focused, especially on how students' previous capacity influenced their science learning. She also could explain students' declining attitude toward science. Knowledge of students' science learning that influenced Shu-May's teaching were that she increased her thinking about and applied different instructional representations, and emphasized concepts and related variables to students in her teaching.

D. Shu-May's thinking on content knowledge became focused and more related to the goals of junior high school physical science textbook. Based on the low ability of the students she taught, she reduced the amount of content covered in her teaching.

In Shu-May's mind, the purpose of her teaching was to reach the goals of the junior high school curriculum, which she believed should be very practical for her students. Thus, all the content knowledge should be relevant and useful to the students in their daily lives.

In Shu-May's senior year, she spent 27 minutes in introducing five different types of velocity calculation problems in class with an emphasis on calculation. In asking her view on chemistry, she described the different disciplines, such as organic, inorganic, analytic, and physical chemistry, and provided detailed descriptions of each discipline.

Toward the end of the study, Shu-May constantly mentioned that the students' low ability made her select a few simple concepts to teach. For instance, in introducing the law of constant composition, Shu-May taught students:

> Shu-May: Let me introduce the law of constant composition. What is the law of constant composition? [She put the following statement on the board]
>
> Law of constant composition: H_2O
> Tap water --- Water
> Sea water --- Water H:O
> River water --- Water Ratio of weight
> Underground water --- Water
>
> [Shu-May started to explain to students]
>
> Shu-May: ... No matter where the original sources of the water, as long as you extract it, pure water will always be H_2O. Do you understand? No matter what the original sources of the water are, as long as we extract it, it will always be pure water.... So the mass between hydrogen and oxygen is 1:8.... It is constant. No matter where the sources of the water are, the weight ratio between hydrogen and oxygen is always 1:8.... Let's turn to page 164[she read from the textbook]. We used experiment to prove the ratio between hydrogen and oxygen in the water. What is the ratio?
>
> SS: 1:8.

This example showed how Shu-May tried to reduce the difficulty level of the concepts and tried to simplify the content for the students. In this case, she only asked the students to remember the ratio between hydrogen and oxygen in water, and carbon and oxygen in carbon dioxide. These two examples were borrowed from the textbook. Except for teaching what was in the textbook, Shu-May did not use calculation problems to show students the law of constant compositions in other complicated chemical compounds.

Toward the end of the study, when interviewed about what chemistry is, what the important concepts in chemistry are, and how chemistry related to other disciplines, she only described what was listed in the junior high physical science curriculum, and never mentioned the additional content in her college chemistry courses. The same responses were obtained when interviewing her on the topic she was teaching. What concerned her most was how to introduce science concepts in a simple way that could be appreciated by her students.

The above findings were also found in studies of other preservice Taiwanese science teachers (Tuan, 1996b) during their senior year of practicum courses. These preservice teachers related what they had learned in the chemistry department and the topic they were teaching. However, after one-month of classroom teaching experience, these teachers' responses to the previous questions shifted to closely following the content knowledge listed in the junior high school physical science textbooks; the relevance of college chemistry to junior high school textbook topics did not seem to greatly influence their science teaching. Shu-May and other pre-service chemistry teachers indicated "what you have learned in the chemistry department is too abstruse to teach in junior high school physical science."

The changes in Shu-May's thoughts about content became more and more focused on the junior high school curriculum. In the beginning of the study, although Shu-May thought teaching should relate to students' needs, her awareness was not reflected in her thinking or teaching of particular content topics. Toward the end of the study, Shu-May would constantly question the difficulty level of the concepts, and decided to teach simple concepts without extensive explanation.

2. Factors influencing Shu-May's PCK development

Analyzing Shu-May's data from her senior year to first year of teaching, the researchers identified many factors which influenced the development of her PCK.

A. Shu-May's perceptions toward science teaching and students' science learning influenced each other and reinforced her presentation of science concepts in a verification way.

Shu-May's teaching was characterized by using the verification method of introducing science concepts from her senior year to first year of teaching; this was influenced by her beliefs about science, epistemology, pedagogy and her perceptions of students' science learning.

Although she did not have any problems with classroom discipline and students' learning ability in her microteaching experience, she thought the best way to present content was by using a "traditional teaching method." During Shu-May's internship experience, she started to be concerned about students' learning abilities; however, her perceptions regarding the students' learning and ways to maintain the students' motivation reinforced her continuous in using verification ways in teaching.

In a low-ability learning environment where classroom discipline problems occurred easily, Shu-May believed the best way to present content was to use simple and repetitious ways to present her content knowledge to the students. The students' achievements in her science class declined as the amount of calculation problems increased on the school tests, due to students' lack of arithmetic ability and their lack of motivation. Shu-May tried to solve these problems by spending time helping them to appreciate the substance of science concepts and using verification instruction to have the students memorize the content knowledge to help them obtain higher achievement scores. Achievement scores were the indicators Shu-May used to check students' understanding; it also became the goal in Shu-May's teaching.

> Shu-May: Their (students) backgrounds were not good, they did not know. So, you have to force them to memorize some facts.
> Researcher: What is your orientation toward physical science teaching?
> Shu-May: Helping them understand and then helping them get good grades. (Int 930929)

She seemed to treat science as a body of terminology (or factual knowledge) for students to know. She also thought that students' mastery of previous knowledge would influence their learning of new knowledge; this reinforced her use of teaching strategies to help students memorize scientific terminology.

B. Shu-May was insensitive in judging the appropriate goals of the lessons and the students' needs for understanding, which made her content representations beyond the students' comprehension level.

An important feature of PCK is to identify the importance of the goal of the topic to match the students' level of understanding, and then decide the appropriate instructional methods to reach the goal of the chapter (Shulman, 1986). Although Shu-May increased her thinking and practicing regarding the representations of the content to students during the investigation period (see Table 1), she did not effectively judge the appropriate level of content knowledge, the goals of lessons, or identify the comprehension levels of the students; these conditions made her content explanations and representations exceed the comprehension level of her students.

When the researcher discussed with Shu-May the importance of addressing categorizing skills for the students, she responded:

> I only taught them what was addressed in the textbook. I did not tell them the goals of this chapter. (Int940321-07)

> In the unit on density, Shu-May described:
> I kept teaching the students the formula D=M/V....My colleagues did not tell me I have to teach M=DxV or V=M/D... I found a problem in a reference book about the density of mixed solutions; I really don't know whether I should teach this problem or not. If I did not teach it, then I did not address any important part in this unit. If I taught it, I was afraid that the students could not understand it. (Int930929-15)

If students understood the concept of density, they could apply the density concept to many situations. Thus, the teaching emphasis should have been placed in various representations for students to construct density concepts instead of helping them memorize different forms of the density equation.

Several variables influenced her teaching. Shu-May's previous tutoring experience in college influenced her in constructing a novice view of the junior high school physical science curriculum. She thought being familiar with the concepts covered and organized in the junior high school textbooks was the goal of the curriculum. Helping students succeed on school examinations was considered by Shu-May to be a more important goal than helping students to understand science concepts and applying them in their daily lives. These factors influenced her in defining her goals for the lessons.

Another variable influencing her teaching was her insensitivity in judging students' needs for understanding. Analyses of Shu-May's questions in her senior year and her quizzes in the first year of teaching indicated most of Shu-May's questions and quizzes were at the memorization level, such as write down the Chinese name for sodium, and write down the chemical formula for water. Fewer than half of the students could reach a passing grade (60 points) on her quizzes. When students faced calculation problems, most of them gave up trying. We interviewed Shu-May about the reaction students had, and she related students' motivation to their confidence in achievement in the science class. Her thoughts of using quizzes was that they could both help her check students' comprehension and help students success on the school examinations. She believed that after having success on school examinations, students' motivation toward learning science would be sparked. Therefore, Shu-May thought that frequently conducting quizzes would push students to memorize scientific terminology in order to get higher scores on the examinations. When Shu-May saw students' failing on these tests, she was unable to diagnose the reasons students did not understand the concepts. Therefore, she could not identify more appropriate ways to present content to these students.

C. Shu-May showed evidence of comprehending concepts and procedures related to pedagogical knowledge in her college methods courses. Her inability to apply them to her teaching situation and later lack of recall of them, however, indicated she did not develop a functional understanding or use of much of the pedagogical knowledge taught.

Analysis of Shu-May's teaching performance showed that her teaching strategies did not change during the investigation period. The only change was in the frequency of some of her teaching activities, such as showing more concrete objects and using drawings or daily-life events to explain concepts.

As mentioned before, the first author had covered many science teaching methods such as lab teaching, conceptual teaching, discrepant event teaching, learning cycle and creative science teaching in the chemistry teaching methods. The author tried to use discussion and role modeling in order for the preservice teachers to appreciate the meaning and application of each teaching method. When she was studying these teaching methods, she could explain and discuss ideas with her classmates. In Shu-May's report, it seemed that she was familiar with these teaching methods. One example shows Shu-May's assignment on her perception of the learning cycle:

> In planning the lesson, a teacher has to think of the students' perception, and then provide a learning environment and teaching resources, let the students conduct labs and learn concepts, and provide opportunities for the students to discuss ideas so that they can apply the concepts to new situations... The role of the teacher is to diagnose, facilitate, and provide a learning environment. (assignment-014)

Unfortunately, toward the end the of the study, Shu-May could not remember most of the teaching strategies or pedagogical knowledge from her college courses related to thinking, talking and performing related to her teaching.

> Researcher: Can you think of any teaching methods learned in college for preparing you in teaching?
> Shu-May: All the theories learned in college seem remote to me. Maybe I have integrated all the pedagogy learned in college or I have totally forgotten it. I do not know... I have forgotten the learning cycle you just mentioned. (Int940321-03)

Researchers could not trace the topics covered in the methods courses to her classroom teaching. What she often taught in the class represented content knowledge for students to quickly appreciate and remember. Any conceptual change teaching methods, discrepant events, or learning cycles were rarely found in Shu-May's teaching. Shu-May did not develop a functional use of most pedagogical knowledge taught in her college courses; therefore, she was unable to apply it in her first-year of teaching.

D. The culture norms Shu-May perceived in different teaching contexts either reinforced or impeded her perception and performance in science teaching.

In Cochran's model (Cochran, *et al.*, 1993) teachers' knowledge of culture and environment also influenced the development of their PCK. Feiman-Nemser & Floden (1986) defined teaching culture as "embodied in the work-related beliefs and knowledge teachers share - beliefs about appropriate ways of acting on the job and rewarding aspects of teaching, and knowledge that enables teachers to do their work (p.508)."

In Shu-May's senior year, she was enrolled in a context where chemistry content knowledge learning was the top priority. In addition, all the students she faced were her classmates; no learning problems or classroom discipline problems occurred in the teaching context. Her perceptions of using the traditional lecture style to present science matched with the existing teaching culture, which reinforced her to mainly address in-depth content explanations in her two microteachings. Shu-May's idea of helping students overcome their learning difficulties at this time was by re-teaching many times until students could understand the meaning. She was not involved in a context that had any pressure, time limitations, or a prescribed curriculum pace.

However, when she was enrolled in her practicum school, the environment where examinations, competition and covering a prescribed curriculum at a set pace were practices and norms very similar to those described in several research reports (Abell & Roth, 1992; Brickhouse & Bodner, 1992; Sanford, 1988), Shu-May tried to adapt to these practices and culture norms. As Shu-May explained to the author why she could not re-teach to confirm students' understanding, she said:

> [In the beginning] I was concerned about whether students understood the concepts or not. If they did not understand, I would teach them again and again, until they grasp at the concepts. But I can not use this way now. I was too idealistic before... I realize the students' ability was low beyond my imagination. No matter how simple a concept, there were always some students who did not understand it... School also provided a prescribed curriculum pace, and examinations, I have to catch up to the prescribed curriculum. That problem is a reality problem. (Inv931104-02)

In addition, Shu-May's perceptions of using achievement scores to motivate students to learn reinforced her adaptation to the cultured norms. This teaching culture and her perceptions toward teaching and learning further reinforced her thinking that helping students get good grades on examinations was her main goal in teaching. These goals could also provide intrinsic motivation for teachers to choose teaching activities designed to foster achievement (Mitchell, Ortiz, & Mitchell, 1982). These goals also influenced Shu-May to help students memorize science concepts instead of helping them appreciate the substance of the concepts and how science concepts could apply to their daily lives.

IV. Discussion and Conclusions

Investigation of the nature of a beginning Taiwanese science teacher's PCK revealed three features. These are integration, relevance, and specificity. Toward the end of the study, Shu-May's thinking and performance in teaching had more integration of content, students and pedagogy. She also tried to make content representation more relevant to the students. Relevancy also influenced Shu-May to match content teaching with the students' level by teaching simpler content using repetition. However, Shu-May's thinking regarding the importance of content relevancy did not necessary reflect her ability to appropriately present content to the students' level. Thus, there are some discrepancies between what Shu-May thought and her appropriate teaching performance. In terms of the specific nature of PCK, Shu-May's knowledge of students changed from a general view of students' learning to a more specific understanding of their content learning ability. Her content knowledge also changed from a general view of the physical science discipline to specific descriptions of what students should know on each topic. Again, the above features of the development of Shu-May's PCK revealed the tendency of Shu-May to think about and improve her teaching. There often is a discrepancy between what teachers say they would like to do and their teaching performance, in other words, they lack the functional knowledge to transfer what they know into appropriate teaching performance. Science teacher educators need to help preservice and beginning science teachers not only to think of the important issues related to PCK but also to help them perform functional PCK in their teaching situation.

The development of Shu-May's PCK from her senior year to the first half of her teaching year was what Berliner (1988) termed, the "novice stage." That is, Shu-May still used certain rules -- the verification teaching strategies to teach content, even though she was aware of the low ability of her students. She tried to use different instructional representations on her students but lacked understanding and awareness for judging the appropriateness of the representations. On the other hand, Shu-May's increasing knowledge of the students started her to think about the teachability of the content; her use of steady and simplified content teaching strategies in the class were in line with Kagan's (1992) model on the acquisition of knowledge of students, shifting attention to students, and developing standard procedures. However, Shu-May's constructed knowledge that related to students' science learning was not appropriate to what really caused the students' science learning problems.

Applying Tuan's (1996c) microscopic views of the development of Shu-May's PCK, her teaching strategies were organized into introducing science concepts from the textbook to help students memorize concepts. Toward the end of the study, her main teaching strategies were the same, but she increased her use of some strategies to help students memorize concepts. Shu-May's instructional representations increased in both variety and frequency, such as providing daily-life examples and illustrations to present science concepts. Shu-May's knowledge of students increased both in students' science learning characteristics and ability. Her thinking and teaching of content became more focused and related to the junior high school physical science textbook. Other features of PCK such as curriculum knowledge and knowledge of assessment did not show obvious development; this might be related to the data collecting procedures which did not address these aspects of data. Future study is needed to address these features of PCK. In terms of the last feature of a PCK -- teacher's knowledge of context, it became one of the factors influencing Shu-May's PCK development, and is discussed later.

Shu-May lacked recall of functional pedagogy knowledge learned in college. Her thinking on content knowledge became focused and more related to the goals of junior high school physical science textbooks, and her knowledge about students increased in both students' science learning characteristics and ability. These three domains of knowledge integrated together influenced her in thinking and performance in instruction of the teaching context. Of course, there is no strong evidence to say Shu-May's pedagogy and content knowledge disappeared, but it is evident these two domains of knowledge were not functional when she thought of and performed PCK. One way to think of Shu-May's decrease of thinking content and pedagogy knowledge might be due to her learning experience in college. She memorized instead of making sense of this knowledge; therefore, it was easy for Shu-May to forget concepts and use was likely never functional.

Factors influencing the development of Shu-May's PCK were her perceptions toward science teaching and students' science learning, insensitivity in judging appropriate goals of lessons and students' understanding, declining retention of pedagogical knowledge, and the different cultural norms she perceived in different teaching contexts.

Shu-May's PCK revealed her view of the nature of science. Her perceptions of science seemed to be that of a logical positivist: that growth in knowledge occurs through accumulation (Abimbola, 1983). This perception reinforced her representation of the scientific knowledge in logical sequential ways and her use of the verification method in presenting science content. A modern view of the nature of science, such as temporary, inquiry and societal nature of scientific knowledge (AAAS, 1993) was not addressed in Shu-May's teaching. She did not present the syntactic and substantial nature of the content discipline (Grossman, Wilson, & Shulman, 1989; Shulman, 1986) to her low ability students, which might have impeded her in using a variety of ways to represent science content instead of simply using lecture style. The current chemistry teacher education department did not offer experiences with these aspects of science to beginning science teachers. The teacher education program could address the nature of science and the syntactic and substantive nature of science disciplines in the science content courses; this might help beginning science teachers or future preservice science teachers to gain more understanding of the nature of science and the nature of content discipline and facilitate the development of their PCK.

Shu-May's inadequacy in judging the ability of her students to learn science, such as what students can know, what they need to know, and how to help them learn science strongly influenced her teaching. Although Shu-May gained some knowledge of students, she still needed to gain understanding of some essential components that directly influenced the students' science learning in order to know how to use appropriate ways to teach content. Because Shu-May could not diagnose her students' learning ability and needs, she had difficulty in selecting appropriate lesson goals.

Shu-May's declining retention of pedagogical knowledge learned in college and her probable lack of functional pedagogical knowledge influenced her to use the same teaching strategies. If Shu-May could have remembered the teaching strategies taught in the methods course, then when she faced students' with low motivation in science learning, she could have applied other teaching strategies to facilitate students' learning. We think, although Shu-May heard about the kinds of science teaching strategies that could have helped her, these teaching strategies were not necessarily meaningful for her in a functional way. Shu-May did not have opportunities to practice these teaching strategies in teaching contexts. Therefore, she did not know how successful these teaching methods could be of the appropriate ways to use them.

The last factor influencing Shu-May's PCK development was the culture norms she perceived in her teaching. Feiman-Nemser & Floden (1986) addressed a teacher's socialization, investigating the transmission of beginning teachers' beliefs, knowledge, attitudes, and values to the norms of the teaching culture. Shu-May's college learning experience, especially her pedagogical knowledge, seemed inactive in her school experience, corresponding to the findings by Zeicher & Tabachnick (1981). Her view of the students' ability to learn also influenced her content teaching, supporting previous research that pupils play an important role in influencing a teacher's behavior (Zeichner, 1983). Although Shu-May had pedagogical knowledge and could verbalize this knowledge in college, this pedagogical knowledge did not seem to have real meaning for her in the classroom, nor did it become part of her root values; therefore it was easily diluted by the teaching culture. However, as Feiman-Nemser & Floden (1986) have indicated, teachers do not have to passively adopt the norms of the teaching culture; they can also change the culture based on their beliefs and practical knowledge.

Therefore, there are two ways to think about this finding. One is that when Shu-May or other beginning science teachers enrolled in the teacher education program, they had experience in memorizing all the factual knowledge in both the content and pedagogy courses. This factual knowledge was not meaningful for Shu-May. Therefore, she did not apply it to her classroom teaching. It is also possible that courses offered in science teacher education programs did not create an environment for preservice science teachers to question their previous perceptions on the nature of science and on science learning. Therefore, when they taught science in school, they applied what they had experienced as high school students, instead of applying what they learned in the science teacher education program.

V. Suggestions

As we learned from Shu-May in the development of her PCK and the factors influencing her development, we generated the following suggestions for future science teacher education.

Research supported our finding that beginning science teachers give more attention to their pedagogy instead of content (Duffee & Aikenkead, 1992; Lederman & Gess-Newsome, 1991; Tuan, 1993). There were many opportunities for Shu-May to improve her science teaching if she had thought more about the nature of science, and the substantial and the syntactic structure of the content discipline.

Teacher education programs should address the nature of science and the syntactic and substantive nature of science discipline in the science content courses. Teaching methods courses need to address the nature of science and science teaching strategies related to the substance of PCK, such as strategies, appropriate instructional representations, curriculum knowledge, ways to diagnosis students' understanding, and ways to determine students' learning characteristics on different subjects. These emphases would help future preservice science teachers to develop their PCK.

As the finding indicated during the internship experience, the beginning science teacher became aware of the importance of integrating her content knowledge to the students' level of understanding. Hopefully, this teaching condition will create opportunities for science educators to introduce and to help beginning science teachers to construct appropriate PCK bases during their supervision and their regular seminars. Topics could be covered in the internship seminar that could relate to thinking of different instructional strategies, appropriate representations, the nature of science related to science teaching, diagnosing students' understanding, and overcome students' learning difficulties.

To provide meaningful teaching methods for preservice science teachers, we need to arouse their attention to the importance of different domains of knowledge in order to facilitate their developing PCK. As Feimer-Nemser & Folden (1986) illustrated, the most immediate genesis of the teaching culture is the classroom context. A teacher's PCK is influenced by the student-teacher interaction in the classroom. Thus, helping preservice teachers have early field classroom teaching experiences and more discussions on relating content teaching and diagnosing students understanding are ways of improving a teacher's PCK development. Teachers need to have opportunities to practice and reflect on what they have learned in their methods course in order to appreciate the substance of each teaching strategy and various instructional representations. What has not been learned in a useful way can not be applied in the teaching context.

If we can educate preservice teachers such as Shu-May and help them construct appropriate perceptions of their content disciplines, the nature of science, and current science teaching strategies, and help them have a successful experience in learning how to use these science teaching methods in the classroom, we can then expect our future teachers to change the science teaching culture instead of the culture diluting what they have learned in the university. Constructing a professional developmental school where the opportunities, support and freedom to practice an appropriate science teaching culture could also help the beginning science teachers to have freedom to master their science teaching.

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Appendix 1: Interview Protocol

Interview questions at the beginning and at the end of the semester:

1. What does an excellent science teacher mean to you? How do you become an excellent science teacher ?
2. How did you become a teacher? What are your future plans?
3. What kind of teacher do you think you are? You can use a metaphor to explain your answer.
4. What does teaching mean to you? What issues in teaching do you think of often? What issues about students do you think of often?
5. What do you think of often about chemistry? Could you express your thinking about chemistry to me?
6. What do you think of often about physics? Could you express your thinking to me ?
7. What do you think of often about physical science? Could you express your thinking about physical science to me?
8. What are your pedagogical beliefs? What does your teaching look like in an ideal situation?
9. What is your perception of students' physical science learning? Do you have any strategies for changing students' learning habits?
10. What are your expectation on how students should learn?
11. What are the goals students need to reach after taking your physical science courses?

Interview questions before each class teaching:

1. Could you explain the content of this unit? Please explain in detail the knowledge you have on this topic.
2. How do you teach this unit? What's your teaching flow?
3. How do you prepare this unit? What factors did you consider? What kinds of difficulties might you face? How do you plan to solve these difficulties?
4. What do you expect students to learn from this unit? Why?
5. Do you have other ways of presenting this unit?

Interview questions after each classroom teaching:

1. What do you think was covered in this unit? What change would you like to made about the responses you provided in previous interview?
2. How do you view your own teaching?
3. How did students learn in this unit? How did you help them?
4. Do you have other ways of presenting this unit?

一位初任台灣國二理化教師學科教學知識之發展研究

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摘　要

本研究的目的在檢驗一位初任女教師在大四至大五上學期期間，其理化的教學特質與成長。研究的理論架構，採微觀與巨觀的學科教學知識。研究方法採質的研究。資料收集包含教室觀察、晤談與文件收集。研究進行期間，由個案質淑美的大四教材教法與實習課，至大五上學期期末止。資料分析主要採分析歸納法。研究發現顯示，淑美的學科教學知識特質包函教學策略與教學表徵兩部份。她的教學策略主要採用驗證式的方式教授科學概念。淑美的教學表徵包涵，口語表達、解題演練、示範、生活實例、利用口語與圖示等方式。淑美的學科教學知識發展呈現出統整、關聯、與具體的特徵。在研究結束時她的教學思考已經能同時整合學科、教學、與學生。在教學中她試圖將學科知識與學生的理解做關連。雖然她企圖使用不同的表徵使得學生能理解概念，但這些表徵未必能符合學生的理解程度。她的學科知識亦從對理化科課程一般的看法，到學生在每單元大致需瞭解到的目標。最後，影響淑美學科教學知識發展之因素，包括其對科學教學與對學生的知覺，她對於檢驗學生的理解程度與合宜的課程目標不夠敏銳，她本身對教學知識的淡忘，和在不同的教學文化情境中所造成的教學重心差異。文章最後亦對於未來科學師資培育做一建議。

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Identification of the Essential Elements and Development of a Related Graphic Representation of Basic Concepts in Environmental Education in Taiwan

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ABSTRACT

The objectives of the study were: 1. to identify the essential elements of the basic concepts in environmental education for Taiwan; and 2. to develop an easily-understood graphic model to express the interrelationships among the identified essential elements. This study's target population (N=1398) consisted of the Society of Science Education, the National Park Society, the Society of Environmental Protection, and many other concerned individual subscribers of the *Quarterly Journal of Environmental Education*. The Q-Sort technique was used to collect research subjects' attitudes toward environmental concepts. A group of experts assisted in establishing the instrument's face and content validity. A Test-Retest method was used to decide the reliability of the Q-set. A Q-set including 44 concepts was established (mean of Pearson's r=.55). The research instrument was sent by mail to 280 systematically randomly selected samples. A total of 196 (70%) research subjects responded to the survey. R-factor analysis was used to analyze the Q-Sort data response. Six underlying essential elements were extracted and identified. They are: 1. Interaction and Interdependence, 2. Resource Conservation, 3. Environmental Ethics, 4. Environmental Management, 5. Ecological Principles, and 6. Carrying Capacity and Quality of Life. A graphic representation describing the interrelationships among the identified elements was also developed via two rounds of discussion involving an interdisciplinary panel of seven experts in science education, environmental protection, conservation, and environmental education.

Key Words: environmental education, concept, element, Q-Sort technique

I. Introduction

The development of appropriate and effective environmental education programs is one of the most important efforts being made by both the government and society in tackling environmental problems in Taiwan. To convey the entire picture of the status of the environment to the general public and students, the decision makers and planners of environmental education programs should have a clear idea of the major foci and directions for their programs before they formally launch extensive efforts. Similar efforts have been made by western environmental educators such as Entwistle (1981), Stapp (1982), & Roth (1989). Therefore, there is a necessity to provide a simple and vivid graphic representation that can reveal the interrelationship among the essential elements underlying basic concepts (Chou, 1994; Chou & Roth, 1992) used in environmental education in Taiwan. With a representation, environmental education programmers and decision makers can grasp the major directions and incorporate them into their education programs more easily. Moreover, this effort can help environmental education practitioners conduct and implement environmental education programs more efficiently and effectively.

To develop environmental education at either the formal or non-formal level has become a basic step for an integrated effort made by any country in tackling various environmental problems. It is also believed that the development of environmental education in different countries will "require the development and teaching of the environmental philosophy and related concepts at every point in the formal and non-formal education process" (Schmieder, 1977). However, before meaningful approaches can be initiated to educate children and adults about environmental matters, questions such as "what should the main focus and major concerns of environmental programs be?" and "what should students know about the environment?" must be clearly answered (Chou, 1992; Townsend, 1982; Yang *et al.*, 1988).

Basically a concept is a way of grouping objects or events in terms of essential similarities. However, concepts are not evaluative (Entwistle, 1981), especially abstract concepts related to the environment which are very difficult to define clearly by simple concepts. Thus, learners have to "build up their own understanding, which thus acquire a personal meaning" (Entwistle, 1981) of those concepts relating to the total environment. Therefore, it is necessary to identify the most essential elements beyond those environmental concepts for appropriate use in environmental education. For example, tremendous progress has already been made in the U.S. in identifying the basic concepts that can be used in environmental education at different levels (Allman, 1972; Ballard, 1989; Brennan, 1986; Ronfeldt, 1969; Roth, 1969; Visher, 1960; White, 1967). Moreover, knowledge of the underlying structure beyond those concepts has also been accumulated (Bowman, 1972; Chou, 1992; Isabell, 1972; Townsend, 1982). However, when applying the research results in developing practical environmental education, the specific conditions in different countries, such as the economy, politics, culture, etc., should be carefully considered (United Nations Educational, Scientific, and Cultural Organization [UNESCO], 1990).

The necessity of developing environmental education in Taiwan did not become an important issue until the late 1980s. Accompanied by the rapid development of the economy, environmental degradation gradually emerged and attracted the attention of the whole society. In addition to large scale pollution abatement measures launched by the government, a comprehensive research program on environmental education was launched by the National Science Council (NSC) of the Republic of China (R.O.C.) in July 1987 (Wang *et al.*, 1987). Many studies have been undertaken in Taiwan since then (NSC, 1989; 1990; 1992). However, very little effort except Chou's (1992) study has been directed toward determining the essential elements that are appropriate for the environment of Taiwan (Chou, 1989; NSC, 1990). It is also believed that with a simple and easily-understood representation, environmental educators should be able to get the whole picture of the concerns related to environmental education. Although some studies have attempted to identify basic concepts in environmental education (Chou, 1989; NSC, 1990; 1992), research specifically focusing upon identifying the essential elements of environmental education and its related graphic representation have been very rare in Taiwan. Such information is essential for environmental education related instruction, teacher training, curriculum development, program planning, and policy formulation in Taiwan.

1. Statement of the Problem

This study is focused on understanding the perceptions that are held by experts in and practitioners of environmental protection, conservation, science education, and environmental education in Taiwan regarding the basic concepts that are appropriate for environmental education. The question posed in this study was: What are the essential elements and their related graphic representation appropriate for environmental education (K-16) as perceived by randomly selected samples of concerned professionals in Taiwan?

2. Objectives of the Study

The objectives for this study were:

(1) To identify the essential elements underlying the important environmental concepts as perceived by experts in environmental protection, conservation, science education, and environmental education in Taiwan.

(2) To develop an easily-understood graphic representation describing the interrelationships among the identified essential elements.

II. Methods

1. Population and Sampling

The target population of this study was professionals who were concerned about the environment especially with regard to education. Owing to the great difficulty in identifying all such individuals in society, names listed on the directories of The Society of Environmental Protection, the National Park Society, the Society of Science Education, and individual subscribers of the *Environmental Education Quarterly* were used as the accessible population to form the sampling frame (n=1398). A systematic random sampling method was adopted to select samples from the frame. Two hundred and eighty subjects were randomly selected for participation in this study.

2. Instrumentation

After extensive review of the related researches and considering the purpose of the study, it was decided that a structured type of Q-sort that used forced sorting (a normal distribution with a specified number of cards in each pile) and R factor analysis could appropriately meet the needs of this study. Several interdisciplinary panels of experts with expertise in environmental management, conservation, environmental education, and science education were consulted during the research instrumentation stage and assisted the researcher in developing the research instrument. At the beginning, six interdisciplinary review panels from the areas of environmental management, conservation, and environmental education were asked to help solidify the initial concept base which was originally developed by the researcher (containing 57 concepts). Through discussion, the panelists reached agreement on reducing the number of concepts in the pool from 57 to 50. Afterwards, a pilot test was conducted. At this stage, eleven experts from different fields but all concerned about the environment were asked to use the Q-sort technique to sort the cards twice (with a one week break in between). Six concepts which had low or negative values of the calculated Pearson's r were deleted from the original Q set. The final Q set containing 44 concepts was used in the formal research instrument during the following data collection stage. Experts also helped to review the content of the questionnaire and the sorting instructions. Through the field test and pilot test (test and retest method was used) mentioned above, the face validity, content validity, and reliability (mean of Pearson's r=.55) were established. The basic components of the research instrument used in the data collection stage included: 1. a complete Q set (44 different environment related concepts, each printed on a card), 2. clearly stated and easy to follow sorting instructions, and 3. a questionnaire inquiring about the background of each respondent.

3. Data Collection and Analysis

The data collection process of the survey was conducted following Dillman's (1978) suggested steps in the Total Design Methods (TDM). All the mailings were sent out by regular first class mail. Totally, three followups were sent to the subjects in order to increase the response. One week after the first mailing, the first followup was delivered. A two-week break was allowed between the later followups. Totally, 196 subjects (70% of the samples) responded to the survey and returned their research packet.

Research subjects were asked to follow the sorting instructions to sort the 44 small cards in the Q set. The easily followed sorting instructions were a very essential tool in order for obtaining data which could be analyzed and were necessary to meet the criteria and satisfy the purpose of the study. By consulting related researches (Chitwood, 1977; Chou, 1992; Townsend, 1982), the researcher of this study developed sorting instructions which were used in the data collection stage. The instructions directed the research subjects to manipulate and sort the 44 cards in the Q set. These cards were to be placed into seven different piles (labeled 0 to 6) in terms of their relative importance ("6" being the most important pile, "0" being the least important pile) for environmental education, with a specified number of cards in each pile. One key question they were to ask themselves when they sorted the cards was: "What should our students know about the environment?" The score for each statement was calculated according to the numeric label of the pile to which it belonged.

The major analytical instrument which was used in the data analysis stage was a statistical package program, used on a Macintosh computer, called SYSTAT (Version 5.2 SYSTAT, Inc.). R Factor analysis with a VARIMAX rotation on the data collected from the samples was used to obtain essential elements.

III. Results

1. Factor Analysis Results

The collected responses of the Q-sort results (the scores of each statement) were used as the basis for R factor analysis. In order to get a significant factor through the calculation process, several standards were considered and applied in selecting the significant factor (Chou, 1992). First, to be a significant item in a factor, its factor loading had to be equal to or greater than three times the standard error of a zero correlation, i.e., $3/\sqrt{n}$ where n is the number of items in the Q set (Schlinger, 1969). That is, for this study, the value of a significant factor loading had to be equal to or greater than $3/\sqrt{44}$. Thus, a decision was made to use .45 as the minimum standard for this study to determine whether a factor loading was significant. Second, a significant factor had to have at least two or more statements. The third consideration was the proportion of the total variance explained by the last factor to be retained. Researchers have set one, five, or ten percent as the standard in different studies, and it was further stated that "...one may set the criterion at whatever level is considered substantively important" (Kim and Mueller, 1978). Four percent was established as the minimum for this standard. The fourth consideration was the criteria of interpretability, which is a crucial step (Kim and Mueller, 1978). Using factor analysis with an orthogonal (Varimax) rotation on data obtained from Q-sort responses of research subjects, six factors were identified and treated as essential elements met the first objective set forth for this study.

Overall, six factors were extracted from the factor analysis. These factors were then treated as essential elements underlying the 44 environmental concepts in the Q set. Altogether, they could explain 35.0 percent of the total variance (Table 1).

The six extracted factors and the corresponding concept statements with rotated factor loadings are shown in the following tables.

Table 2 provides information about the concept statements and corresponding rotated factor loadings of Factor I. Factor I could explain 9.4 percent of the total variance.

Table 3 provides information about the concept statements and corresponding rotated factor loadings of Factor II. Factor II could explain 7.07 percent of the total variance.

Table 4 provides information about the concept statements and corresponding rotated factor loadings of Factor III. Factor III could explain 5.60 percent of the total variance.

Table 5 provides information about the concept statements and corresponding rotated factor loadings of Factor IV. Factor IV could explain 4.83 percent of the total variance.

Table 6 provides information about the concept statements and corresponding rotated factor loadings of Factor V. Factor V could explain 4.09 percent of the total variance.

Table 1. Results of Factor Analysis of the Q-sort Results

Factor	Eigenvalue	Added (%) Variance	Coumulative Percent (%) of Total Variance
I	4.13	9.40	9.40
II	3.11	7.07	16.47
III	2.47	5.60	22.07
IV	2.13	4.83	26.90
V	1.80	4.09	30.99
VI	1.77	4.01	35.00

Table 2. Factor I and the Corresponding Concept Statements with Rotated* Factor Loadings

Concept	Rotated Factor Loading
40. All living organisms have the right to live on earth and compete to survive. This right can not be denied, no matter whether they can be used by humans or not.	-.58
10. During different kinds of human settlement and development, human have the responsibility to maintain the living environment in order to upgrade the welfare of all people.	.54
9. Humans are also a part of the nature. We are not superior to other living organisms.	-.53
17. Responsibility for conservation should be shared by individuals, business and industries, special interest groups, and all levels of government and education.	.51
23. Living things are interdependent on each other and their environement.	-.49
41. Energy, its production, use, and conservation, are essential in the maintenance of our society.	.47

*Varimax rotation

Table 3. Factor II and the Corresponding Concept Statements with Rotated* Factor Loadings

Concept	Rotated Factor Loading
39. Natural resources are limited and should never be wasted.	.59
33. Most natural resources are vulnerable to depletion in quantity, quality, or both.	.54
6. To manage environmental pollution, prevention beforehand is more effective than compensation and treatment afterwards.	.54
25. Natural resources affect and are affected by the material welfare of a culture and directly or indirectly by philosophy, religion, government, and the arts.	-.51
28. The natural environment is irreplaceable.	.47

*Varimax rotation

Table 7 provides information about the concept statements and corresponding rotated factor loadings of Factor VI. Factor VI could explain 4.01 percent of the total variance.

2. Naming the Essential Elements

Obtaining six essential elements which were extracted from the 44 environmental concepts in the

Table 4. Factor III and the Corresponding Concept Statements with Rotated* Factor Loadings

Concept	Rotated Factor Loading
4. We are ethically responsible to other individuals and society, and to that larger community, the biosphere.	-.69
11. Humans have a moral responsibility for their environmentally related decisions.	-.65
35. Forests are an important part of the global ecosystem that supports us and of which we are a part. Deforestation (clearing an area of all trees) will cause an immediate loss of wildlife habitat and natural resources. Long-term effects may include desertification and climate change.	.55

*Varimax rotation

Table 5. Factor IV and the Corresponding Concept Statements with Rotated* Factor Loadings

Concept	Rotated Factor Loading
30. The management of natural resources to meet the needs of successive generations demands long-range planning.	-.62
1. Humans should play a role in understanding nature and to cooperating with other constitutents of nature.	-.60

*Varimax rotation

Table 6. Factor V and the Corresponding Concept Statements with Rotated* Factor Loadings

Concept	Rotated Factor Loading
3. In any environment, one component such as space, water, air or food may become a limiting factor.	-.63
13. The environment is the sum of all external conditions and influences affecting organisms. The environment may be divided into biotic (living) and abiotic (non-living) components.	-.56

*Varimax rotation

Table 7. Factor VI and the Corresponding Concept Statements with Rotated* Factor Loadings

Concept	Rotated Factor Loading
37. There is a maximum human population corresponding to each resource base. The population cannot exceed this level if a satisfactory standard of living for all people is to be maintanined.	-.66
44. Increasing population and per capita use of resources have brought about changed land-to-people or resource-to-population ratios.	-.65
27. Family planning and the limiting of family size are important if overpopulation is to be avoided and a reasonable standard of living assured for future generations.	-.59
26. Humans should never do whatever they want. Everything we do will have an unexpected influence on other people and living organimsm either now or in the future. Therefore, humans should always use environmental ethics as a basis for making value judgments.	.48

*Varimax rotation

Q set was only half the work required to reach objective one set forth for this study. In order to make the results of factor analysis meaningful, the second step--a very crucial and essential step--was to give each identified essential element a name. With meaningful names given to the identified elements, researchers and environmental educators could then communicate effectively and efficiently with target audiences about the major concerns/directions of environmental education in terms of the content core. Five professionals from the areas of the environment, education, and conservation were asked to provide assistance during the factor-naming stage. Two rounds of written discussion among panelists were adopted at this stage. They carefully looked into the meanings and implications of the concepts of each element and expressed to each other their opinions about the appropriate names and their meanings. After two rounds of exchanging and sharing opinions, they finally reached a consensus on the names of the essential elements. They were named as follows:

(1) Interaction and Interdependence;
(2) Resource Conservation;
(3) Environmental Ethics;
(4) Environmental Management;
(5) Ecological Principles; and
(6) Carrying Capacity and Quality of Life.

Furthermore, the identified essential elements' implied meanings were listed and discussed as follows:

1. Interaction and Interdependence

Within the environment, living and non-living elements always interact and are interdependent with each other. Moreover, living organisms, humans, and even different segments of the human society are interacting and interdependent with each other. Therefore, we have to understand the unique characteristics of interaction and interdependence existing in the environment.

2. Resource Conservation
   Human society and its cultural development are close tied to natural resources. Since the natural resources on earth are limited, humans have to use them carefully by considering the sustainability of natural resources.
3. Environmental Ethics
   Humans are also members of the whole ecosystem. Therefore, we have to have a positive attitude, proper behavior, and a sense of responsibility with respect to the earth and all other living organisms.
4. Environmental Management
   Human welfare depends upon the appropriate management and maintenance of the environment. We have to use the environment carefully in order to avoid damaging the earth and harming future generations.
5. Ecological Principles
   Understanding the nature and principles of ecology is essential to foster positive attitudes and actions among people to maintain the proper balance, stability, and integrity of the ecosystem.
6. Carrying Capacity and Quality of Life
   The size of the human population and human behavior have direct influence on natural resources, environmental quality, and the quality of life. Therefore, we have to adequately regulate the size of the human population and control human behavior's impact on the environment.

3. Developing the Graphic Representation

The second major focus of this study was to develop a simple and easily-understood graphic representation which could be used as a communication tool to help concerned educators understand the major concerns of environmental education and the interrelationships which exist among them. It was hoped that through the model's graphic representation of the interrelationships existing among the identified underlying essential elements, environmental education programmers and policy makers could then grasp the whole picture of the major concerns of environmental education easily. In order to reach this goal, the researcher invited seven experienced professors from the areas of environmental management, environmental education, conservation, and education to form an interdisciplinary panel to participate in a panel discussion on the model-development stage in this study. During this stage, each panelist fully expressed his or her ideas on the paper in and returned them to the researcher by mail without meeting the other panelists personally. The researcher was the one responsible for compiling all the ideas and feedback then sending to each panelist to serve as a basis for next round of discussion. Each expert was given all of the written information about the results of factor analysis for reference. Experts were asked to draw a diagram on paper to illustrate the interrelationships that existed among all the identified essential elements. They were also asked to write down their explanation of the meaning expressed by the representation and their reasons for drawing it the way they did. All the results were integrated and compiled by the researcher and provided to each expert in the panel. After two rounds of extensive written discussion, the panelists finally reached on agreement concerning the graphic representation. This is shown as follows (Fig. 1).

IV. Discussion

Apparently, the results of this research essentially reveal the need for a comprehensive and systematic understanding of the entire environment which emphasizes learning about all the facets of the environment and related issues, and does not only focus on teaching and learning compartmental and partial knowledge of the environment.

The meanings conveyed by the essential elements and graphic representation may be directed toward the development of a basic understanding of the earth's environment and related ecological concepts. The developed model emphasizes that understanding should be based upon the characteristics of interaction and interdependence existing among the living organisms, the environment, humans, and different sectors of society. Humans should also establish a new ideology that includes a positive attitude, value judgments and treatment of the earth and all

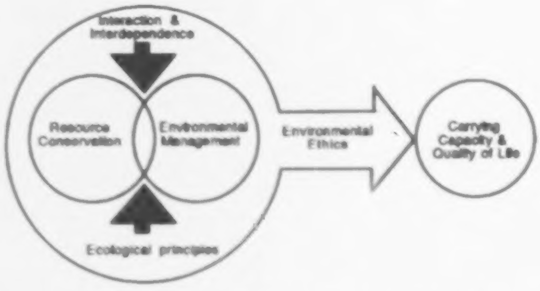

Fig. 1. Graphic representation of the essential elements of hte environmental education related concepts.

organisms with equality and respect. Only through the integration and incorporation of the knowledge, attitudes, and values mentioned above can we then efficiently use limited natural resources by considering the earth's sustainability, and manage and solve environmental problems in an effective manner. Only by solving environmental problems at their root causes and lessening humans' negative effects on the environment can the quality of the environment be maintained. In this way the end goal of achieving a better quality of life can be reached.

V. Implications and Recommendations

Corresponding to the processes, technique, and results of this study, several implications and recommendations for environmental education, future study, and other researchers are given as follows:

1. The six essential elements identified in this study are a very important means of clarifying the major focus of environmental education development. They imply that the major task of environmental education is to investigate all facets of the environment instead of being limited to one or two directions' narrow perspective.
2. The graphic representation developed here can be provided as valuable reference for the development of future environmental education curriculum and instructional materials for different age groups. The essential elements in the graphic representation can be used as a major axis leading toward the direction of developing different levels' environmental curriculum and instructional materials.
3. The findings of this study may be provided to the concerned governmental agencies and non-governmental organizations as a good reference for the determination of the major directions of environmental education efforts such as environmental education policy planning, program planning, teacher training (both pre- and in-service training), and curriculum development.
4. Because of the limited time and resources available, it is suggested that use more diverse groups of people as the population. Further study should consider different target groups such as:
    a. government officials in education and environmental conservation;
    b. school teachers (primary and secondary levels);
    c. representatives of non-governmental organizations;
    d. representatives of industry.
5. Further study may also use Q-factor analysis (treating the subjects as the independent variables) to analyze the data in order to understand any different types of attitude underlying the research subjects' views concerning the environment.
6. Further research can incorporate on investigation of the association between the attribute variables and the elements identified into the research design in order to provide more information on the field of environmental education.
7. Comparing the normal distribution method used in the forced-sorting Q-sort process of this study to the rectangular distribution Q-sort method used in an earlier similar study (Chou, 1992), the researcher discovered that there is no great difference between the two kinds of method when considering the survey's response rate. Similar future research can take either normal or rectangular distribution as the sorting method in the Q-sort process.

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鑑別環境教育重要概念的最基本要素並發展其相關之圖形表徵

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摘 要

本研究的目的是爲了能夠找出符合我國現況的環境教育概念隱含的基本要素（essential elements），並將其以一容易理解的圖形表徵呈現出來。研究主要採用調查（survey）研究法。研究對象涵蓋層面頗爲廣泛，包括來自科學教育學會、國家公園學會、環境保護學會以及其他關心環境教育發展的學者專家。利用 Q-Sort Technique 來收集受訪者對於各環境概念的態度反應，也使用基本資料問卷來收集受訪者的基本背景資料。研究工具 Q set 經由專家參與評審訂定其表面效度（face validity）及內容效度（content validity），並經 pilot test 的前後兩次測試達到最終 44 個環境概念的整體信度測試（Pearson’s 平均 =0.55）。研究工具組由郵遞送達經系統隨機抽樣所得之樣本共計 280 名，回收率達 70%。回收的資料使用 R 型因子分析法（R-factor Analysis），得到最後的六個基本要素，分別是 1. 互動與互賴（Interaction and Inerdependence），2. 自然資源的保育（Resources Conservation），3. 環境倫理（Environmental Ethics），4. 環境管理（Environmental Management），5. 生態原理（Ecological Principles），以及 6. 承載量與生活教育、環境保護、保育、環境教育等方面的專家經過了兩回合的討論，研擬出了一個簡易圖形，用來表示這六個環境教育內容的基本要素之間的相互關係。

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A Beginning Biology Teacher's Professional Development
-- A Case Study --

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Abstract

The purpose of this case study was to describe and identify if knowledge of students was an important foundational component of PCK (Pedagogical Content Knowledge) for a beginning biology teacher. Interpretive research methods described by Erickson (1986) were applied in this study. Multiple data gathering methods, both qualitative and quantitative, were used to collect data from 55 consecutive periods of classroom observation across a complete academic year. Data obtained and used included field-notes, after-class interviews, classroom interaction analyses, and student questionnaires. Triangulation techniques were employed to enhance the validity of the findings. Data indicated that the novice teacher could create an active classroom environment, but that her poor knowledge of students prevented her from managing more effective communication in the classroom. In the instructional activities, the teacher always failed to find appropriate analogies, metaphors, and representations for students' construction of knowledge. For this novice teacher, knowledge of students seemed to be an important foundational component; her lack of this knowledge limited her PCK growth.

Key Words: beginning biology teachers; knowledge of students; professional development; pedagogical content knowledge; secondary school science; junior high schools

I. Introduction and Background

What does it mean to be a qualified beginning teacher? In Taiwan, we still know very little about the differences between effective beginning teachers and effective experienced teachers. In the early history of science education in this country, teacher education only emphasized knowledge of subject matter. During the past few decades, student teachers have been told to put emphasis on the effectiveness of general pedagogical methods, such as questioning skills, wait time, small-step questioning, inquiry training, open-ended laboratories, and the assessment of student performance independent of subject-matter.

Shulman (1986, 1987) suggested that teaching expertise should be described and evaluated in terms of *pedagogical content knowledge* (PCK). Cochran, DeRuiter and King (1993) applied their model of *pedagogical content knowing* (PCKg) to teacher education to generate hypotheses for future applied and theoretical research. According to this model, PCKg includes four components: knowledge of pedagogy, knowledge of subject-matter, knowledge of environmental contexts, and knowledge of students. Content-specific pedagogy has been defined to understand the knowledge, skills, abilities, and interests students bring to the study of subject matter (Arreaga-Mayer & Greenwood, 1986; Confrey, 1990; Corno & Snow, 1986; Swisher & Deyhle, 1987; Wallace, 1986). Reynolds (1992) indicated that this includes students' conceptions and possible misconceptions of particular topics in the subject matter, students' beliefs about their ability to succeed in the subject matter, students' academic self-concept, students' nonverbal and sociolinguistic backgrounds, the expectations students' families have, and students' personal experiences.

Other researchers see PCK as comprising the most appropriate forms of representations for the subject matter for a given group of students (metaphors, explanations, illustrations, examples, etc.), which make the subject matter understandable and interesting to students (McDiarmid, Ball, & Anderson, 1989; Wilson, Shulman, & Richert, 1987). Reynolds (1992) suggested that at the time of formal summative evaluation for licensure, we should expect beginning teachers to be able to:

1. Plan lessons that enable students to relate new learning to prior understanding; 2. develop rapport with students; 3. establish and maintain rules and routines; 4. arrange the physical and social conditions in the classroom; 5. represent and present subject matter in ways that enable students to relate new learning to prior understanding; 6. assess student learning using a variety of measurement tools; 7. reflect on their own actions in order to improve teaching (P.7).

Measurement of these expectations was not within the scope of their study. However, they provided a basis for describing a beginning teachers' professional growth.

The purpose of this study was to investigate a beginning biology teacher's professional growth and to describe and determine if "knowledge of students" was a critical component of pedagogical content knowledge for this teacher.

II. Methodology and Setting

Interpretive research methods described by Erickson (1986) were used. Multiple qualitative and quantitative data gathering methods and triangulation were used to enhance the validity of the findings.

1. Participant

Miss Cho (anonymity), a female beginning teacher, graduated from the Department of Biology, National Taiwan Normal University (NTNU), in 1992. She taught four grade-7 classes of biology in a junior high school located in a western suburb of Taipei, the capital city of Taiwan. She had a three-week student-teaching experience with grade-7 biology classes in the university laboratory school before graduation. She comes from an "educational family" of a large city in Southern Taiwan; both parents were school teachers. Miss Cho was enthusiastic about teaching biology.

2. Site

The junior high school was three years old. Many school buildings were still under construction. The grade-7 students used classrooms borrowed from an elementary school nearby. There was a fence surrounding the building to separate students of these two schools. There were no laboratories or audio-visual studios in this school. Classrooms were equipped with only basic equipment, such as several sets of microscopes, petri-dishes, and beakers. Many items, such as models and audio-visual equipment, were not available. There were 50 students in the observed class with approximately equal numbers of male and female students. The majority of the students came from mining or laborer families. A majority of them were eager to seek opportunities for further schooling after graduation from junior high school.

3. Data Collection

The qualitative data were collected mainly by means of participant observation, teacher interviews, and document gathering following the procedures introduced by Gallagher (1991). Miss Cho was observed for 55 lessons spread across a complete academic year, 1992-1993. All observations were video-tape recorded. Before or after class interviews were conducted with the teacher to obtain information about her beliefs related to her instructional behavior. The interviews were also tape-recorded. Teaching plans, teaching aids, students' work sheets and test papers related to the observed instruction were preserved in the form of photocopies or photo pictures to be analyzed. Some quantitative data were also collected. Teacher-student interactions and the frequency of student-initiated questions were recorded, and the teacher's patterns of response to the student-initiated questions were also analyzed. The teacher's responding patterns were categorized into four categories based on a model which was used to analyze teachers' questioning skills in the a previous study (Taiwan Provincial Kaoshiung Teachers' College, 1974):

A. Gives definitive strict responses, such as definitions, principles or rules, as defined in textbooks or encyclopedia without any consideration of students' prior knowledge or everyday life experience.
B. Gives analogies or metaphors which relate to the student's everyday life experience.
C. Gives direct yes/no responses to confirm student's ideas but without any further explanation.
D. Confusions or algorithms given for solutions without an understanding of the logical relation between the problem and solution.

At the end of the academic year, a questionnaire was administered to students to assess the student's attitudes toward the teacher.

4. Data Analysis

The data base consisted of both qualitative and quantitative data collected from field-notes of classroom observations, interviews and documents. Vignettes were obtained to describe the teacher's behavior and possible explanations or tentative assertions of the behaviors. Then, the vignettes were sorted, and frequency analysis was proceeded. Finally, associated with quantitative data collected from the classroom interaction analyses and the results of a questionnaire on students' attitudes toward the teacher, analytical reduction and triangulation were employed to enhance the validity of findings.

5. Triangulation

The validity of a qualitative study can be enhanced by triangulation (Patton, 1990). The primary form of triangulation for this study was " triangulation of sources" (Patton, 1990; p.464). Data triangulation was accomplished mainly by using after-class interviews. By comparing data, including both qualitative and quantitative data collected from classroom observations, interviews, and documents (e.g., test papers, students laboratory notes and worksheets of class activities), the consistency of statements was checked.

III. Results and Discussion

In this section, the performance of participants in the observed classes are discussed. The participants' concerns and perceptions as expressed by the participants are presented and supported through interview data and the results of document reviews. The results and assertions are discussed in four parts of professional components as below:

1. Alternative Representations

Assertion 1: The beginning teacher appeared to understand the need for creating lessons that were appropriate for the subject matter; however, she did this in rather superficial ways due to her lack of knowledge of students.

PCK is a type of knowledge that is unique to a teacher and also is the form of knowledge that makes science teachers rather than scientists (Gudmundsdottir, 1987a,b). According to the academic record provided by the Department of Biology, NTNU, Miss Cho always had excellent performance in both subject matter knowledge (in the biological sciences) and pedagogical knowledge (in science education courses) during her four years of study. However, at the beginning stage of her teaching career, she could not always interpret her students' questions properly. Her students always expressed their questions freely in her biology classes, but Miss Cho seemed to have difficulty in answering students' questions at critical points. An example from a Photosynthesis lesson (S=Student; T=Miss Cho) is quoted:

> S: Miss Cho, there is water existing in the first stage ("light" reaction). Why does a plant have to produce water in the second stage ("dark" reaction) ?........ Why can't water be utilized directly?
> T: (repeating student's question in her own words) Do you mean why can not the water in the second stage be utilized in the first stage?
> S: No, I mean......
> T: (restating the question in other words) Why is water produced when we have water at the beginning?
> S: Yes,......
> T: (smiling) I see......
>
> (Field Note: 10/21A)

Miss Cho explained in a rather strict, definitive way; she repeated a paragraph from the textbook. As predicted, students were not satisfied. Then she used an analogy:

> T: Three good friends (an analogy of a water molecule, 2 H atoms and one O atom), are standing together hand in hand; after the chemical reaction, one of them (an H) leaves and a new friend (another H) joins to the other two.
>
> (Field Note 10/21B)

The students seemed to be satisfied with this explanation. She mentioned "changing head" as an analogy. Ebert (1993) argued the importance of the teacher's knowledge about the learner as a constructor of knowledge and how this knowledge has the potential to impact instruction and, subsequently, learning. The grade 7 students in Taiwan did not have background knowledge about chemical reactions. This "change head" analogy was not an appropriate one. Miss Cho may have had some difficulty thinking of an appropriate representation at that moment. This kind of difficulty was observed often in the " *Cell* (10/7)", "*Leaf and Conduction* (11/13)", "*Tropism of Plants*" (12/23), and "*Heredity* (4/16)" lessons. In the "*Tropism of Plants*" lesson, Miss Cho explained the tropism of plants by using a "running track in a stadium" analogy:

> T: Look, one side of a plant stem grows faster, the other grows slower, then, what will happen? Another example, ...(drawing a picture of a running track in a stadium)......, now, you have physical training. Given the right to choose, which runway will you select?
>
> S: Inside one!
>
> T: Yes! You will pick the inside track, because the distance of the inside track is shorter than that of the outside one. Then, think about this, this side of a stem with less growth hormone grows slower, and the other side has more growth hormone. Thus, one side grows faster, the other side slower, both sides grow, now, they are growing at same time, ... one faster, the other slower......, then this 'person' growing faster has to bend over to this side, the other 'person' grows slower, therefore, it bends......
>
> (Field Note:12/23)

The analogy employed may be appropriate for some imaginative students, but Miss Cho neither clarified the similarities and differences between these two ideas, nor did she make connections to students' preconceptions; therefore, the students were even more confused.

Assertion 2: Teacher knowledge of students' prior knowledge and life experience may form a foundation for the teacher to create appropriate analogies to present concepts for her students in an intelligible way.

PCK includes knowledge of the conceptual and procedural knowledge that students bring to the learning of a topic. It also includes knowledge of techniques for assessing students' understanding and diagnosing their misconceptions (Carpenter, Feonnema, Peterson, & Carey, 1988). A field-note taken from the *Photosynthesis* lesson is an example of this problem:

> S: Miss Cho, why does a plant need energy from the sun instead of doing the job by itself?
>
> T: Because without chemical energy, there is no power to separate the *three good friends*......
>
> S: That is right, I mean, if there is no chemical energy, can plants do the job?
>
> T: No, plants can not do it.
>
> S: Does the plant need only water made of two H atoms and one CO_2?
>
> T: Do you mean water in the second stage?
>
> S: Can't that be reused?
>
> T: Do you mean that the produced water could be reused by plant?
>
> S: Yes.
>
> S: Miss Cho, I meant, does *it* need only the water made of two H atoms and one CO_2?
>
> T: Who is "*it*"?
>
> S: The plants. (Miss Cho was confused, so she checked the textbook and tried to make sense of the student's question.)
>
> S: He asked, "Do the two H have to bind with CO_2 and then be utilized?"
>
> S: No, I meant, "Does the plant need only the water made of two H atoms and one CO_2?" (Students laugh)
>
> T: I know what is your question now. The water produced can be reused by the plant......
>
> (Field Note: 10/21B)

At the beginning, Miss Cho could not understand what the student was asking. After a while, Miss Cho decided the question was, "Can the produced water be reused?" Then she gave the students an answer. However, in the student's mind, the produced water was made of two H and a CO_2!

(Interview 10/21C)

In the after-class interview, she was astonished when the researcher pointed out this misconception of her student. She said:

> T: Really! Did he say that? (water made of two H atoms and one CO_2). No wonder students laughed at him!
>
> T: You must know their (her students') strange talk with funny gestures and accents!
>
> (Interview 10/21 D)

Most of her students came from miner families. For the city-born Miss Cho, the students were talking a strange language. She always had difficulties understanding them. Miss Cho urged the students to know if the water produced (through photosynthesis) could be used by the plant (for "next" photosynthesis). In the student's mind, the water produced was a different kind of water (made of two H and a CO_2)!

(Interview 10/21 C)

This kind of misunderstanding, caused by her confusion over what the student was saying, occurred during almost every lesson across the whole school year. An effective teacher creates lessons that enable students to connect what they know to new information. The teacher also knows how to tailor the subject matter to the students. *Photosynthesis* is one of the most abstract subjects in grade-7 biology. This subject contains the concepts of "energy transformation", "chemical synthesis" and even "thermodynamics". It is not an easy task for even a veteran teacher to create appropriate representations. Nevertheless, an effective teacher should , at least, be sensible to students' misconceptions.

2. Knowledge of Students

Teachers differ from scientists, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. An experienced science teacher's knowledge of science should be organized from a teaching prospective and be used as a basis for helping students to understand specific concepts. One of the four components of teacher knowledge described by Cochran (1991) is the teachers' knowledge of students, including knowledge of students' abilities, learning strategies, ages and developmental levels, attitudes, motivations, and prior knowledge of the concepts to be taught (Cochran, 1991).

Assertion 3: The beginning teacher successfully created a classroom climate in which students were motivated to learn. She developed an excellent rapport with most of her students. However, she saw the students as a group and neglected individual needs.

Miss Cho established an open classroom climate that enabled her to collect students' ideas and information. The students felt free to ask questions and speak during class. Some students asked questions frequently in class, and others would talk to Miss Cho directly. The researchers tabulated the frequency of selected classroom interactions.

The frequency of student-initiated questioning increased through the first month of school (0.15-0.71 times per minute) and stayed at around 0.3 times per minute (0.23-0.69 times per minute) in the following months during the first semester. She had much more student-talk time in her observed class compared to the average teacher-talk time of 70 percent reported by Delamont (1990).

Miss Cho created a classroom climate in which students wanted to learn. She developed excellent rapport with her students. Her students' images of a good teacher were like someone who knew everything about the subject matter. It may have made Miss Cho act as a knowledgeable scholar who knew all the answers to questions raised by students.

The questionnaire administered at the end of the semester also indicated that students felt free and willing to communicate with Miss Cho (Table 1). Although Miss Cho always misjudged some student-talk, she was quite willing to listen to students, and enriched her knowledge of students.

However, she always saw students in the class as a group and neglected individual needs. In the after class interviews, concerning interaction problems in her biology class, she always complained that some students would not cooperate with her. During the first semester, one of the students, David, frequently asked questions that made Miss Cho very uncomfortable. The researchers interviewed David after class and made sure that he did not do that on purpose (Field Note: 4/16). He indicated that he asked questions because he was really confused and eager to clarify his concepts (Interview: 6/25).

From one of the after-class interviews in the second semester, we sensed Miss Cho's negative attitude toward David's questioning behavior. In May, during the second semester, we found that David was

Table 1. Students' Metaphors of Miss Cho

Metaphors	Number of Students
• The source of knowledge --a master mind --a dictionary --an encyclopedia --a mine of wisdom	31/50
• A kind lady full of patience --a mother --a nursemaid --an elder sister	23/50
• A shy pretty lady	2/50
• A lady of responsibility	1/50

not asking questions anymore. This made Miss Cho feel better. The researchers talked to Miss Cho and expressed concern that David was a slower learner and that was why he asked questions. However, Miss Cho still insisted on her perception that David did not carefully listen to the lectures and asked silly questions without thinking. In her mind, David was one of the students who never *cooperated* with her.

We thought from the data analyzed that Miss Cho did establish an open classroom for students to explore their problems but only created a group of 10-12 very active target students. She did not always make sense of the information she received from other students. Sometimes, she misjudged the information from those students. Miss Cho formed her knowledge of students through classroom interaction. But her knowledge of students was not related to reality and, thus, affected her teaching as Elbaz (1983) described.

3. Values in PCK

Assertion 4: The students' social background and value of schooling, e.g., learning for entrance examinations, affected the beginning teacher's value of education and, consequently, influenced her teaching practices.

The role of values in the development of PCK was examined through interviews and classroom observation of four expert high school teachers by Gudmundsdottir (1990). Analysis indicated that the teachers' value orientations to their subject matter influenced their choice of content pedagogical strategies and their perception of students' instructional need.

In the *Heart, Vein, and Circulation* lessons, Miss Cho talked about her experiences in previous teaching about the structures of the human heart. She realized that the students only tried to memorize the terms for the structure of the heart and ignored which blood vessels connected with which parts of the heart. If the figure of the heart in the textbook was altered, the students would be confused (interview on 11/20). Miss Cho pointed out this phenomena to her students and said, "Don't memorize only the locations"; however, the students were still confused by what she said.

T: When you are taking an examination, the figures on the examination sheets are not necessarily the same as this one. Therefore, don't just memorize the locations; instead, you have to memorize each part (of the heart) and how they are connected to each other. All those (blood vessels) connecting to ventricles are arteries, such as the aorta which connects to the left ventricle (sticking "Aorta" on the blackboard). The aorta here is the same as the "main artery" you have learned in *Health Education*. The aorta connects to the left ventricle, and the pulmonary artery connects to the right ventricle (sticking "pulmonary artery" on the blackboard)......This one. All the blood vessels which connect to the atrium are veins, such as the pulmonary vein and the superior and inferior vena cava. That's it...... (Miss Cho explained the figure without eye contact with any student.)

S: I don't understand...... T (sticking "pulmonary vein" on blackboard): Can't you get it?

T: Now, see......this figure is very important when you are preparing for an examination; however, the figure in an examination will not always be the same as this one, line one in your textbook...... You, sit down (to a student who tried to ask a question). You can not just memorize where the veins, aorta, pulmonary vein are located; instead, you must know which parts of the heart they connect to ....

(Field Note: 1/20)

At the beginning, Miss Cho drew a figure which was the same as that in the textbook on the blackboard, with the aorta and pulmonary artery crossed to each other. After some dialogue between the teacher and students, Miss Cho drew another figure (with no cross between the aorta and pulmonary artery) and asked one of the students to fill out the names of the structures of the heart. As predicted, the student made many mistakes. Miss Cho reminded the students, "Don't memorize the locations"; however ,the students failed to figure out what she meant. Obviously, the concerns of the teacher and the students were quite different; thus, the students were confused and off-track. In the after-class interview, we found that Miss Cho could not make sense of this problem. She insisted on expressing her concern about the examination. In responding to the researcher's suggestion of " Why didn't you use a three-dimensional mock-up model for a more concrete representation?", she said: " They are not likely to have a three-D model in an examination. I have to teach them how to respond correctly in examinations."

The knowledge base includes the different ways of knowing that are important for teachers and necessary for successful practice. Education, according to Peter (1970), implies transmitting something that is worthwhile in a morally acceptable manner, and being educated means having changed for the better (p.6). Educational philosophers recognize that there is no such thing as value-free education (Gudmandsdottir, 1990).

Miss Cho's values which were related to her PCK influenced her teaching practices. As an example, she provided algorithms to help her students be good test takers. Due to the severe competition to obtain further schooling, she had pressure from students and the school administration. The pressure may have influenced her choice of instructional strategies or representations. She administered short tests or quizzes to her students during almost every class period. The test-items for a class always included the same test-items administered in previous classes. She explained that she had to do that because she was deeply concerned that her students be successful test-takers. The results suggested that Miss Cho's beliefs influenced her teaching practices.

The case below was taken from the *Heredity* lesson. It shows another problem in instructional representation.

T: O.K., another question, a couple would like to have another baby. What is the probability of having a boy with attached earlobes?

S: 1/2......

T: Lily, what's the probability?

S: 1/2

T: 1/2, is that right? Look, what is the probability of having attached earlobes? That is 1/2 (Miss Cho points to the Punnett Square on the board). The probability of having attached earlobes and of having free earlobes are equal, both are 1/2. But the couple want a boy,... the probability of having a boy or a girl is 1/2; therefore, if this couple want to have a boy with attached earlobes, the probability is 1/4. That means when both propositions are true, we multiply, this concept......

S: Why is the probability of gender uncertain?

T: No, the probability of having a boy or a girl is exactly 1/2.

S: Then, why do we get 1/4?

T: I added one more proposition in this case: the baby must have attached earlobes. Another example may be helpful to explain this concept. One department store is having a 20% off sale, and you go shopping. Another smart student will wait for an extra 20% off. When will you go shopping?

S: When there is an extra 20% off.

T: That's right, with an extra 20% off, now we have 36% off. Why? 20% off and another 20% off (writing down 0.8×0.8) is 36% off. Isn't that the better time to go shopping? Both propositions are true, so we multiply them. Got it? You must remember this concept......

S: I don't get the point ......

T: Hands up if confusing, the reason why we multiply, hands up, if you can't figure it out! You are falling asleep! (Many students put their hands up.)

S: Why with an extra 20% off do we get 36% off?

T: 0.8 times 0.8 equals 0.64!

(Field Note: 4/16)

In this case, Miss Cho provided an algorithm to terminate the argument. She explained how to calculate the probability of "both propositions are true" by using the analogy of an extra 20% off in a department store. The students knew that an extra 20% off is cheaper than only 20% off, but they could not figure out that an extra 20% off meant a total of 36% off. In addition to the original problem, "having a boy with attached earlobes", the students had another confusing concept.

The subject matter which the students were arguing about was a concept related to proportional reasoning. According to Piaget's cognitive developmental theory , it is a formal operation skill not usually processed effectively by students until the *stage of formal operation*. Based on research conducted by Lin (1982), only one-third of the grade-7 students in Taiwan have developed this skill. This means that the majority, two-thirds of the students, probably have difficulty trying to understand these ideas. The teacher merely provided a recipe, or an algorithm, without understanding.

4. Professional Growth

As pointed out in assertion (1), this beginning teacher appeared to understand the need for creating lessons that were appropriate for the subject matter and students, but she accomplished this task only in superficial ways. However, Miss Cho still made some progress in her instructional representations.

Assertion 5: Through active classroom interaction, the teacher developed her understanding of students, and this understanding may have contributed to her professional growth.

Her students felt free to express their problems during the biology classes. As a matter of fact, this is rather unusual in most classes in Taiwanese schools. Taiwanese students seldom ask questions during their classes. An international study found that Taiwanese students had a strong tendency to rely on " taught method" for problem solving and were seldom encouraged to ask questions in their classes (Yang, 1993). However, in Miss Cho's classes, as described in the previous paragraphs, the average number (times) of student-initiated questioning (S-i-Q) during the first semester was 10 times per period (50 minutes). As shown in Table 2, more than one-third of the questions in the biology classes were S-i-Q. Regrettably, Miss Cho always gave direct answers to almost all S-i-Qs. No question was followed with another question by the teacher. She tried to answer all the questions raised by the students. This probably is one of the reasons why students saw her as a "master mind" (a resourceful person) (Table 1).

The teacher's patterns of response to the S-i-Q were analyzed. As shown in Table 3, 19% of the responses to S-i-Q were strict definitions or principles as defined in textbooks. An example shown below was the typical "strict definition" response pattern:

> (In responding to a student's question about *Photosynthesis*) The O (oxygen) in the initial H_2O (water) is hit by chemical energy; the rest of two H (hydrogen) atoms bind together with O in CO_2 and, thus, produce $C_6H_{12}O_6$ (glucose) and a new water molecule.
>
> (Field Note 10/21A)

36% of the S-i-Q were answered using analogies and metaphors employed from the students' everyday life experiences, such as the "changing head" analogy for the chemical reaction in *Photosynthesis* and "running track in a stadium" analogy for tropism as described in Assertion 1. Another 25% of the

Table 2. Student-Initiated Questions in a Class Period (50 minutes)

Month	September	October	November	December	January	Average
Average Q+A Period (%)[a]	29	44	38	23	23	31.4
Average Number of S-i-Q[b]	8	10	13	12	7	10.0
% of S-i-Q of all questions raised	38	23	35	48	33	35.4

a. Average time allotted for "questions and answers" (per 50-minutes-class period).
b. Average number of Student-initiated questions raised.

Table 3. Teacher's Responding Patterns to Student-initiated Questions During 13 Consecutive Class Hours

Pattern	Percentages per total S-i-Q raised												
1. Strict Definitions	60	25	34	33	10	6	36	–	20	14	17	–	–
2. Analogies or Metaphors	–	50	–	17	60	25	21	50	60	57	41	40	50
3. Confirmation	–	25	33	25	10	25	36	38	–	29	50	20	40
4. Confusions and Gave Algorithms	40	–	33	25	20	44	7	13	20	–	16	40	10
Date	4	9	18a*	18b*	21	6	13	20	11	23a*	23b*	6	8
Month	Sep	Sep	Sep	Sep	Oct	Nov	Nov	Nov	Dec	Dec	Dec	Jan	Jan
Lessons		Living World		Cell		Digestion	Leaf		Stimulus		Irritability		Respiration
	Biosphere		Organ		Photosynthesis			Circulation		Behavior		Homeostasis	

*18a,b & 23a,b: 2 consecutive class hours in the same day (September 18 & December 23) questions were answered using yes/no or right/wrong pattern. Responses to 20% of the S-i-Q were confused and, in most cases, algorithms were used as described for the *heart structure* and *Heredity* lessons in Assertion 4. This performance was rather "normal" for a beginning biology teacher (Taiwan Provincial Kaoshiung Teachers' College, 1974; Yang, 1993).

In the very beginning stage of her teaching, some degree of confusion and inappropriate representations were likely. She always responded to her student-initiated questions by giving strict definitions quoted from the students' textbooks and in some cases even quoted from college textbooks! This made the students more confused. In other cases, she just asked students to memorize something, or gave them an algorithm to satisfy them. After several weeks, she seemed to recall what she was taught in her *science education* courses at NTNU and tried to employ analogies or metaphors for the S-i-Q. As shown in Fig. 1, her *strict definition* responding pattern decreased; on the other hand, application of *analogy* and *metaphor* patterns increased across the whole semester. Some analogies used were not very appropriate for her students and were presented in superficial ways. Data analyzed indicated that in spite of her problems she did achieve professional growth. Also, she reduced the number of strict definitions and appeared to increase the number of confirmations. These data may indicate that she was gaining confidence in her S-i-Qs.

IV. Conclusions and Implications

Data from 55 periods of classroom observation and many interviews indicated that Miss Cho developed rapport with her students and established an active open-classroom. She allowed greater freedom of action during the class. Students were comfortable expressing their ideas and problems during the biology classes. However, very frequently, Miss Cho misjudged the information she received through students' questions and statements. In many cases, she ignored her students' prior-knowledge or experiences that would have helped them acquire new knowledge.

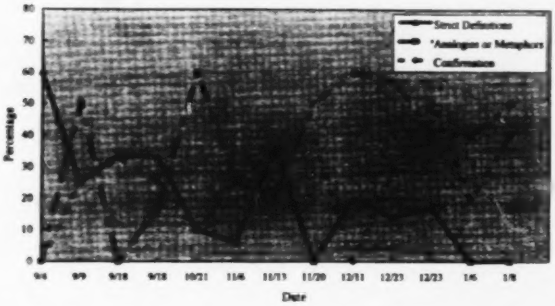

Fig. 1. Teacher's patterns of response to student-initiated questions.

Constructivism suggests that teachers should first teach students *how to learn*, and, secondly, *what to learn*. It has also been suggested that language cannot be a means of transferring information in teaching; it should be used to cope with our environment and help us make sense of our world (Lerman, 1989; Fosnot, 1989; Steffe, 1991; Reynold, 1992; von Glasersfeld, 1984, 1989, 1991). Obviously, Miss Cho and her students frequently failed to communicate with each other effectively. Although Miss Cho created an active learning climate, her poor knowledge of students inhibited her PCK performance as identified by Cochran, DeRuiter, and King (1993). She frequently did not use appropriate representations to help students master concepts as indicated by Zheng (1992). Miss Cho achieved some professional growth in her patterns of responding to student-initiated-questions. However, her ability to seek appropriate representations and help students develop metacognitive strategies remained superficial.

Reynolds (1992) indicated that a beginning teacher needs time to learn about the school culture and students; a teacher's knowledge develops through the processes of continuous learning and reflection. Miss Cho needed a longer period of time to increase her competence; she also would probably have gained from more guidance. Wallace and Louden (1992) have indicated that knowledge development in teachers is a gradual process, rather than one composed of sudden leaps of insight. A teachers' repertoire of instructional representations constantly expands as a result of "thousands of hours of instruction and tens of thousands of interactions with students" as described by Berliner (1987).

Effective teaching is the product of self-organization. Data obtained here suggest that a teacher without substantial knowledge of her students is not likely to employ her taught subject matter knowledge and pedagogical knowledge effectively in a real classroom situation or to create a favorable learning environment for her students. Knowledge of students that can aid effective teaching should be learned through real classroom experiences. *Knowledge of students* seems to be a foundation needed for Miss Cho's PCK growth (Fig. 2).

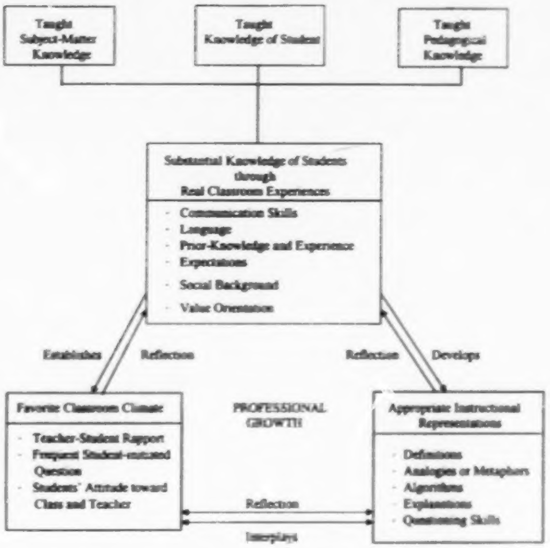
Taught Subject-Matter Knowledge
Taught Knowledge of Student
Taught Pedagogical Knowledge
Substantial Knowledge of Students through Real Classroom Experiences
- Communication Skills
- Language
- Prior-Knowledge and Experience
- Expectations
- Social Background
- Value Orientation
Establishes
Reflection
Reflection
Develops
Favorite Classroom Climate
- Teacher-Student Rapport
- Frequent Student-initiated Question
- Students' Attitude toward Class and Teacher
PROFESSIONAL GROWTH
Appropriate Instructional Representations
- Definitions
- Analogies or Metaphors
- Algorithms
- Explanations
- Questioning Skills
Reflection
Interplays

Fig. 2. The beginning biology teacher's knowledge of student and professional growth model.

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初任生物教師專業成長之個案研究

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摘　要

本研究採用詮釋性研究法，以研究一位初任生物科教師的專業能力發展過程中，學生知識在學科教學知識各項構成因素中的重要性。由連續觀察共達55 詳個案教師所擔任生物課以及課前或課後的晤談，及有關教學各項文件檢視所收集質的數據，再配合教室互動分析及學生問卷中所得量化數據，並進行三角校準以考驗研究效度。研究結果顯示這位新手教師雖能成功地營造生動活潑的教學環境，卻因缺乏有關學生實質知識，使她不能創造更爲合適的教學表徵，包括類比和隱諭以助學生們建構新的知識。以這位個案教師而言，有關學生的知識似乎就是教學專業技能發展的關鍵性基礎。

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